ATTACHMENT D – SCIENTIFIC AND TECHNICAL BASIS OF THE NUMERIC NUTRIENT CRITERIA FOR MONTANA'S WADEABLE STREAMS AND RIVERS: ADDENDUM 1

Montana Department of Environmental Quality

Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers: <u>Addendum 1</u>

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EXECUTIVE SUMMARY

This document is the first update by the Department of Environmental Quality (Department) to the numeric nutrient criteria recommendations it made in 2008. The science of eutrophication in general and numeric nutrient criteria in particular has continued to advance in the interim years. In addition, the Department has modified somewhat the process by which numeric criteria are derived. In 2008, the Department used ecoregions, stressor-response studies (nutrient as stressor, impact to stream beneficial use as response), and data from reference streams to develop criteria. Various cases studies had established a linkage between nutrient concentrations observed in reference streams and harm to beneficial uses; on average, harm-to-use occurred at the 86^{th} percentile of the nutrient reference distribution. In the 2008 document the Department relied heavily on two percentiles from the ecoregional reference distributions, namely the 75^{th} and 90^{th}, to derive specific criteria for each ecoregion.

The approach taken in 2008 had its shortcomings, however. In some ecoregions the method resulted in criterion concentrations which other data and studies have shown were unnecessarily stringent, while in other ecoregions the method resulted in criteria at concentrations that were too high. The method—albeit simple, consistent, and transparent—limited the Department's ability to derive best-fit criteria for each ecoregion. Fundamentally, the Department considers the combined use of ecoregions, stressor-response studies, and reference data to be a sound approach. But more stressor-response studies are now available and these can better inform the criteria derivation process. As a result, in this addendum there has been less reliance on specific reference-distribution percentiles and much more reliance on regional as well as non-regional stressor-response studies.

The other major change, relative to the 2008 document, is that the Department will not be recommending nitrate (or nitrate + nitrite) criteria for adoption for the control of eutrophication at this time. Only total phosphorus (TP) and total nitrogen (TN) criteria are provided here. Rapid uptake of soluble nitrogen compounds by aquatic organisms (mainly algae and plants) makes these compounds' concentrations quite variable, and difficult to use as ambient surface water criteria. Total nitrogen and TP provide better overall correlation to eutrophication response than soluble nutrients, and are more practical than soluble forms for river monitoring and assessment, total maximum daily loads, etc.

The Department is recommending both TN and TP criteria for stream protection. Phosphorus (P) control is sometimes promoted as the only approach needed to limit eutrophication, this being based largely on the more economical removal of P from wastewater and the assumption that P can be made to become limiting in the waterbody. But data pertaining to streams and rivers indicate that it would be unwise to adopt only P criteria. Mixed assemblages of benthic algae are very often limited by nitrogen or nitrogen and phosphorus (co-limitation) in the region's flowing waters. A P-only approach, in order to work, would require that P standards be set to the background levels observed in our western region's reference sites (e.g., 10 µg TP/L). If the P standard were not set to natural background, and no controls on N were undertaken, then the commonly occurring N limitation or N and P co-limitation would lead to algal growth stimulation nonetheless. Worse yet, in the long term, a P-only strategy would result in highly skewed (elevated) N:P ratios accompanying the low P levels. These management-induced conditions might control green algae biomass but may lead to nuisance blooms of the diatom algae *Didymosphenia geminata,* which has in recent years formed nuisance blooms in rivers and streams in Montana and word-wide.

A balanced and prudent policy would be to reduce both N and P and maintain, as nutrient concentration reductions occur, a roughly balanced (i.e., Redfield) ratio between the two. This is the strategy that has been applied on the Clark Fork River and it appears to be working there. And other researchers in the field are recommending that both N and P need to be controlled to effectively manage eutrophication. Thus, both N and P criteria for wadeable streams and rivers are proposed in this document.

The document has been organized so that readers can quickly locate key information pertaining to an ecoregion of interest. Data specific to each ecoregion is presented on two to three pages. A map of Montana showing the ecoregion in which the criteria apply is shown first, followed by the criteria recommendations, and then a table of descriptive statistics for the ecoregion's reference streams. Then readers will find TN and TP histograms for the reference data, a discussion of the scientific studies (regional and beyond) that were used to help derive the criteria, other considerations pertaining to the derivation of the criteria, and a conclusion with final thoughts about the criteria.

The Department recognizes that within each ecoregional zone there are likely to be some streams with unique characteristics that could render the ecoregional criteria inappropriate. These characteristics include, for example, the presence of a large dam-regulated lake or reservoir upstream, or the upstream influence of a level-IV ecoregion known to have naturally elevated TP concentrations. A few cases have already been identified, and reach-specific criteria for them are presented and discussed in the document.

Below are summarized the criteria concentrations that have been recommended (**Table ES-1**). As was the case in the 2008 document, the criteria should generally apply seasonally.

Table ES-1. Recommended Numeric Nutrient Criteria for Different Montana Ecoregions and Stream Reaches. Related assessment information is also shown.

		Parameter		
Ecoregion (level III or IV) and number, or Reach Description	**Period When Criteria Apply**	**Total Phosphorus (µg/L)**	**Total Nitrogen (µg/L)**	**Related Assessment Information***
Northern Rockies (15)	July 1 to September 30	30	300	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Canadian Rockies (41)	July 1 to September 30	25	350	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Idaho Batholith (16)	July 1 to September 30	30	300	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Middle Rockies (17)	July 1 to September 30	30	300	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Absaroka-Gallatin Volcanic Mountains (17i)	July 1 to September 30	105	250	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Northwestern Glaciated Plains (42)	June 16 to September 30	110	1400	
Sweetgrass Upland (42l), Milk River Pothole Upland (42n), Rocky Mountain Front Foothill Potholes (42q), and Foothill Grassland (42r)	July 1 to September 30	80	560	165 mg Chl*a*/m^2 and 70 g AFDM/m^2
Northwestern Great Plains (43) and Wyoming Basin (18)	July 1 to September 30	140	1400	

Table ES-1. Recommended Numeric Nutrient Criteria for Different Montana Ecoregions and Stream Reaches. Related assessment information is also shown.

		Parameter		
Ecoregion (level III or IV) and number, or Reach Description	**Period When Criteria Apply**	**Total Phosphorus (µg/L)**	**Total Nitrogen (µg/L)**	**Related Assessment Information***
River Breaks (43c)	NONE RECOMMENDED	NONE RECOMMENDED	NONE RECOMMENDED	
Non-calcareous Foothill Grassland (43s), Shields-Smith Valleys (43t), Limy Foothill Grassland (43u), Pryor-Bighorn Foothills (43v), and Unglaciated Montana High Plains (43o)†	July 1 to September 30	33	440	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
INDIVIDUAL REACHES				
Flint Creek, from Georgetown Lake outlet to the ecoregion 17ak boundary (46.4002, -113.3055)	July 1 to September 30	72	500	150 mg Chl*a*/m^2 and 45 g AFDM/m^2
Bozeman Creek, from headwaters to Forest Service Boundary (45.5833, -111.0184)	July 1 to September 30	105	250	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Bozeman Creek, from Forest Service Boundary (45.5833, -111.0184) to mouth at East Gallatin River	July 1 to September 30	76	270	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Hyalite Creek, from headwaters to Forest Service Boundary (45.5833,-111.0835)	July 1 to September 30	105	250	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Hyalalite Creek, from Forest Service Boundary (45.5833,-111.0835) to mouth at East Gallatin River	July 1 to September 30	90	260	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
East Gallatin River between Bozeman Creek and Bridger Creek confluences	July 1 to September 30	50	290	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
East Gallatin River between Bridger Creek and Hyalite Creek confluences	July 1 to September 30	30	300	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
East Gallatin River from Hyalite Creek confluence to the mouth (Gallatin River)	July 1 to September 30	60	290	125 mg Chl*a*/m^2 and 35 g AFDM/m^2

*Refers to benthic algae density.

† For the Unglaciated High Plains ecoregion (43o), criteria only apply to the polygon located just south of Great Falls, MT.

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ACRONYMS

Acronym	**Definition**
AFDM	Ash Free Dry Mass
ARM	Administrative Rules of Montana
Chl*a*	Chlorophyll-*a*
DEQ	Department of Environmental Quality (Montana)
DO	Dissolved Oxygen
HBI	Hilsenhoff Biotic Metric
NB	Natural Background
SOP	Standard Operating Procedure
SRP	Soluble Reactive Phosphate
TDP	Total Dissolved Phosphate
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United States Geological Survey
WMA	Wildlife Management Area
WWTP	Wastewater Treatment Plant

1.0 INTRODUCTION

This is the first addendum to the Department of Environmental Quality (Department) document "Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers" (Suplee et al., 2008). Suplee et al. (2008) addresses methods that were used to derive numeric nutrient (nitrogen and phosphorus) criteria. The science of eutrophication in general and numeric nutrient criteria in particular has continued to advance in the interim years. Thus, this addendum reflects the most up-to-date nitrogen and phosphorus criteria recommendations for the control of eutrophication in wadeable streams and rivers that the Department has so far provided. As these nutrient criteria are refined, it bears repeating that the purpose of water quality criteria and standards is to define a level of a pollutant that will protect beneficial uses. This is the level to which degraded streams need to be restored; streams with water quality better than the criteria are addressed by the state's non-degradation provisions (i.e. ARM 17.30.701 through 17.30.718).

In the 2008 document, the Department used ecoregions (Woods et al., 2002), regional stressor-response studies (nutrient as stressor, impact to stream beneficial use as response), and data from reference streams to derive the criteria. Ecoregions were used to segregate the landscape into zones within which single nitrogen and phosphorus criteria—protective of the streams' beneficial uses and unique to each ecoregion—were recommended. Linkages had been made between harm to beneficial uses and nutrient concentrations which occurred, on average, at the 86th percentile of reference, with a coefficient of variation of ± 13% (i.e., from the 73rd to the 99th percentile; (Suplee et al., 2007). In developing its 2008 criteria recommendations, the Department relied heavily on two percentiles from the ecoregional reference distributions, namely the 75th and 90th (Suplee et al., 2008).

In 2008 the Department used only two different reference percentiles to derive the criteria because there were fewer regional dose-response studies available. Further, the Department believed that it was best to be consistent in the use of reference-percentiles across broad areas of the landscape, because it would be fair and transparent. In retrospect this approach had its failings, however, because in some ecoregions (e.g., the Canadian Rockies) the method resulted in criterion concentrations (6 µg TP/L) which other data and studies have shown to be unnecessarily stringent, while in other ecoregions (e.g., the Middle Rockies) the approach produced criteria concentrations (48 µg TP/L) we now believe to be somewhat too high. The original approach limited the Department's ability to recommend custom-fit criteria for different ecoregions that best reflect the level of water quality needed to protect the beneficial uses of each particular region.

The Department still considers the combined use of ecoregions, stressor-response studies, and reference data to be a sound approach, but in need of modification. New stressor-response studies are now available and we believe these can better inform the criteria derivation process. In this addendum, which documents the Department's updated methods, there will be less reliance on specified reference-distribution percentiles and much more reliance on regional as well as non-regional stressor-response studies. For clarity, we contrast below the approach taken in 2008 (**Figure 1-1**) vs. the approach taken in this document (**Figure 1-2**).

Another concern pertaining to the earlier work was the degree to which all reference sites within an ecoregion were equitably represented. In some ecoregions, a great deal of data has been collected at one or two reference sites and much less data at other sites. In this updated work, we improved objectivity by assuring that each reference site in an ecoregion only contributes a comparable amount of information to the ecoregional dataset; this is reflected in box 3 of **Figure 1-2** and is detailed in **Section 2-2**.

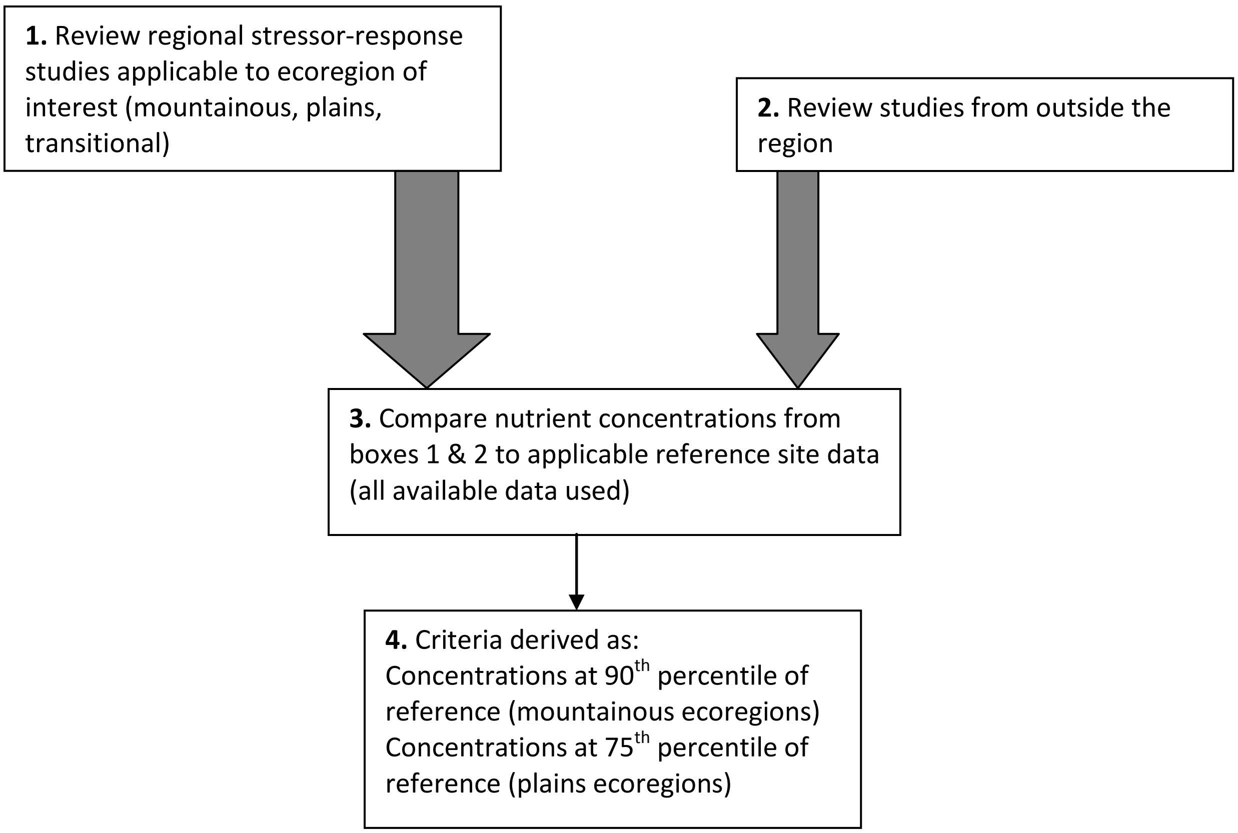


Figure 1-1. Overview of approach used to derive nutrient criteria in 2008 (Suplee et al., 2008). The size of the large grey arrows near the top of the figure represent the relative importance of the two information sources for deriving regional nutrient criteria.

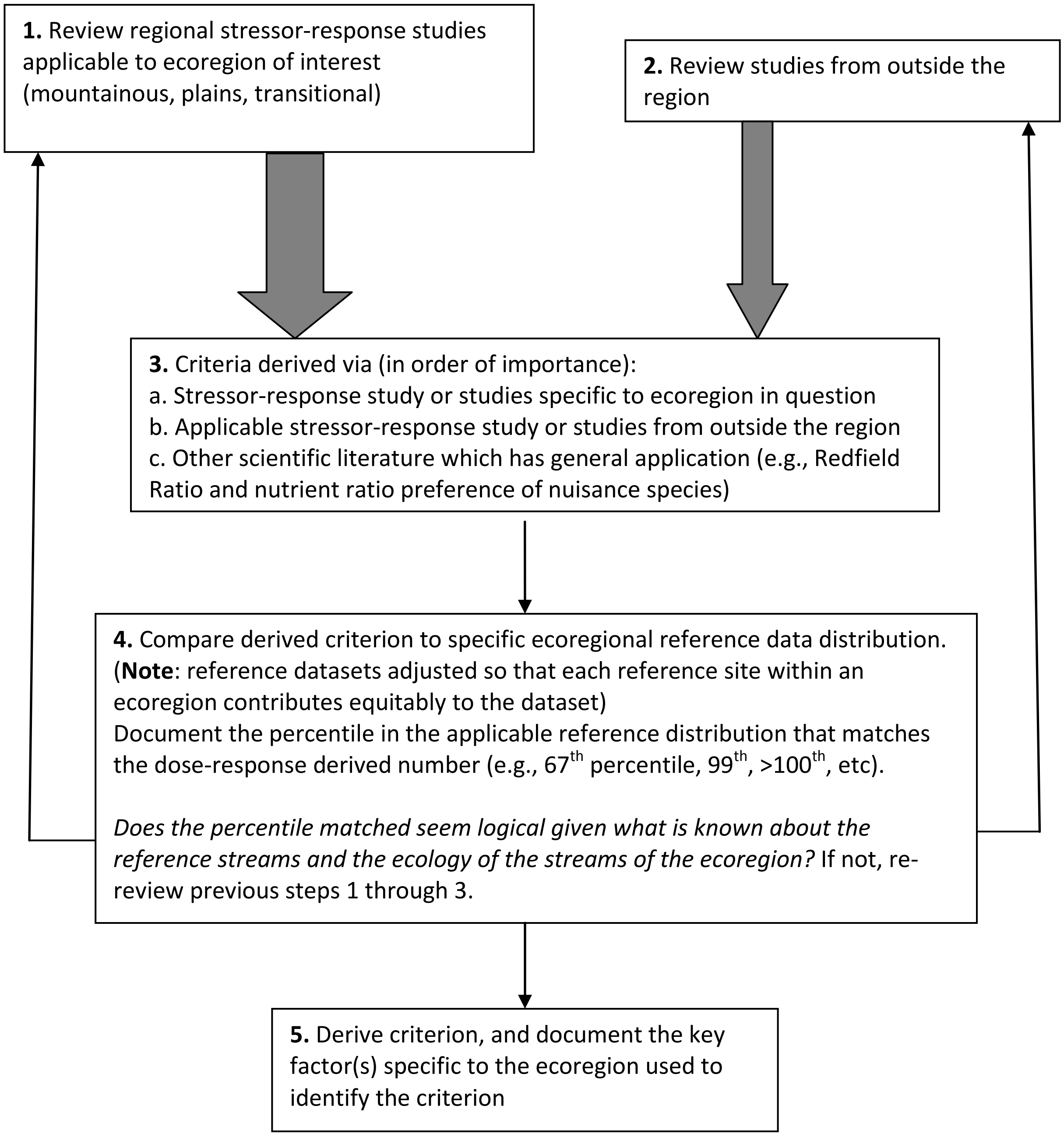


Figure 1-2. Overview of approach used to derive nutrient criteria in this document.
The size of the large grey arrows near the top of the figure represent the relative importance of the two information sources for deriving regional nutrient criteria.

The other major change, relative to the 2008 document, is that the Department will not be recommending nitrate (or nitrate + nitrite) criteria for adoption for the control of eutrophication at this time. Only total phosphorus (TP) and total nitrogen (TN) criteria are provided here. Rapid uptake of soluble nitrogen compounds by aquatic organisms (mainly algae and plants) makes these compounds' concentrations highly variable, and difficult to use as ambient surface water criteria. Total nitrogen and

TP have been shown to provide better overall correlation to eutrophication response than soluble nutrients (Dodds et al., 1997; Dodds et al., 2006; Dodds et al., 2002) and, in terms of water quality criteria, total nutrients are more practical than soluble forms for river monitoring and assessment, total maximum daily loads, etc. (Dodd and Welch, 2000). **However**, the Department strongly encourages the collection of nitrate + nitrite when collecting TN and TP data. The soluble data can often point to specific types of nutrient sources, for example. The Department's Water Quality Monitoring Section will continue to include nitrate + nitrite alongside TN and TP for routine monitoring for nutrients.

2.0 METHODS USED TO DERIVE THE CRITERIA

In the **Introduction** we presented a general overview of the updated process used to derive the numeric nutrient criteria (**Figure 1-2**). In this section, we delve further into the details of these approaches.

2.1 ECOREGIONS AS THE BASIS FOR ESTABLISHING NUTRIENT CRITERIA ZONES

The Department tested the usefulness of ecoregions (Omernik, 1987) as a means to establish nutrient criteria zones; that work is detailed in Varghese and Cleland (2005) and Section 4.0 of Suplee et al. (2008). The Department will continue to use ecoregions as the basis for establishing nutrient criteria zones. Subsequent analysis has further verified that specific level IV (small scale) ecoregions are significantly different from the larger-scale level III ecoregions in which they reside (Varghese and Cleland, 2008; Varghese and Cleland, 2009). In **Section 3.0** of this document we will detail the criteria derived for individual ecoregions be they level III or IV. In general, a level IV ecoregion will only be broken out for nutrient criteria derivation **if** (1) natural concentrations of nutrients in the level IV ecoregion are elevated above concentrations identified as harming uses per the stressor-response studies pertaining to that region, **or** (2) it is a level IV ecoregion that resides along the Rocky Mountain front (or similar environments) and represents a zone with mountain-to-prairie transitional streams.

2.2 CRITERIA IN THIS DOCUMENT APPLY TO WADEABLE STREAMS

The scope of the criteria in this document is wadeable streams. The only substantive change since 2008 pertaining to this topic is the definition of specific rivers and river segments which are not wadeable (i.e., the large rivers). Flynn and Suplee (2010) use a wadeability index (product of river depth [in feet] and mean velocity [in ft/sec]) of 7.2 to segregate wadeable from non-wadeable rivers. During summer base flow these large rivers have mean water depths in excess of 3.15 ft and discharges of 1,500 ft^3/sec or greater. In Montana, rivers with these characteristics are almost always 7^{th} order or higher (Strahler, 1964), and this is consistent with earlier definitions of large rivers based on stream order (Welcomme, 1985). **Table 2-1** shows the non-wadeable large rivers of the state to which the criteria in this document ***do not*** apply. The Department is primarily using process-based mechanistic water quality models to identify criteria for large river segments.

Table 2-1. Large river segments within the state of Montana.

River Name	Segment Description
Big Horn River	Yellowtail Dam to mouth
Clark Fork River	Bitterroot River to state-line
Flathead River	Origin to mouth
Kootenai River	Libby Dam to state-line
Madison River	Ennis Lake to mouth
Missouri River	Origin to state-line
South Fork Flathead River	Hungry Horse Dam to mouth
Yellowstone River	State-line to state-line

2.3 CRITERIA APPLY SEASONALLY, WITH EXCEPTIONS

As before, we recommend that the numeric nutrient criteria for wadeable streams and rivers apply seasonally, during that period when algae growth is peak and ensuing water quality impacts are maximal (i.e., the "Growing Season"). See **Table 2-2** below. For monitoring and assessment purposes, however, a ten day window (plus/minus) on the Growing Season start and end dates is acceptable, in order to accommodate year-specific conditions (e.g., an early-ending spring runoff). Best professional judgment is required to decide if early or later sampling is warranted.

Table 2-2. Start and Ending Dates for Three Seasons (Winter, Runoff and Growing), by Level III Ecoregion.

Ecoregion Name	Start of Winter	End of Winter	Start of Runoff	End of Runoff	Start of Growing Season	End of Growing Season
Canadian Rockies	Oct.1	April 14	April 15	June 30	July 1	Sept. 30
Northern Rockies	Oct.1	March 31	April 1	June 30	July 1	Sept. 30
Idaho Batholith	Oct.1	April 14	April 15	June 30	July 1	Sept. 30
Middle Rockies	Oct.1	April 14	April 15	June 30	July 1	Sept. 30
Northwestern Glaciated Plains	Oct.1	March 14	March 15	June 15	June 16	Sept. 30
Northwestern Great Plains	Oct.1	Feb. 29	March 1	June 30	July 1	Sept. 30
Wyoming Basin	Oct.1	April 14	April 15	June 30	July 1	Sept. 30

Exceptions to the seasonal applicability of nutrient standards will occur when it is known or demonstrated that a stream or river is having a significant influence on a downstream lentic waterbody (lake, reservoir). In such cases, criteria (and nutrient loads) applicable to the lake may apply to a stream draining to the lake, and would apply year round. These situations need to be determined case-by-case, and are beyond the scope of this document.

2.4 Method for Assuring that All Reference Sites are Equitably Represented in an Ecoregion

Assuring that each reference site contributes an approximately equal number of N and P observations to each ecoregional zone has been a Department objective for some years (see Section 6.2.1 of Suplee, et al. (2008)). Since Suplee et al. (2008) was released, the Department continued to target under-represented reference sites and collected data in summer 2009 and summer 2010.

In spite of the targeted field work, there was still a fair amount of inequality in terms of the number of nutrient observations per site in each ecoregion. Therefore, we undertook an additional step in the office using the updated (current through 2010) reference nutrient dataset. We again made use of the Brillouin evenness index (Pielou, 1966; Zarr, 1999) to assure that each reference site in an ecoregion contributes equal amounts of information to the nutrient dataset. For this work, our goal was to achieve an evenness index value (J) of at least 0.9 (90% even) for each ecoregion (be it level III or IV)[3]. This required in some cases that a proportion of observations from heavily-sampled reference sites be excluded from use. This was carried out objectively and independently for TN and for TP, as follows. First, the J value was calculated using all data for a given nutrient (e.g., TP) from all reference sites within the ecoregion in question. If the value was ≥0.9, nothing further was done and all the data were

[3] An alternative (and we consider inferior) approach would be to reduce each sampling site's dataset to a median, and then carry out descriptive statistics on the population of medians for the geographic unit in question (e.g. Middle Rockies ecoregion). But a tremendous amount of information is lost in this process (e.g., the low and high observations). As such, we prefer the evenness index, which (if made sufficiently even) gives each site a roughly equal voice but also retains the vast majority of sample observations so that they can be used in descriptive statistics.

used as-is for descriptive statistics, etc. If the value was <0.9, we identified the over-contributing reference site(s) and calculated how many observations would need to be removed from each in order to achieve a J value of 0.9. Because J measures evenness, reducing many observations from a single over-contributing site was not effective. Instead, a smaller number of observations had to be eliminated from each of the major over-contributors. Once the number of observations to be eliminated from each over-contributing reference site was known, we randomly removed that number of observations from the dataset of each of the specified sites. Finally, the now 'more even' dataset (comprising observations from un-altered sites and the observations remaining from the sites where the random elimination process was applied) was used to generate descriptive statistics.

It should be noted that, in some level IV (small scale) ecoregions, there were only a few references sites and the number of collected nutrient samples was correspondingly low. We wanted to maintain a sample-size minimum of about 12 (Varghese and Cleland, 2008, Appendix H) for these ecoregions in order to sufficiently characterize the reference condition. Therefore, in level IVs that were near to this sample-size minimum, no adjustments using the Brillouin evenness index were undertaken.

2.5 Literature Consulted

A re-review of the relevant scientific literature cited in Suplee et al. (2008) was undertaken, as well as a search and review of various studies and reports that have been released before and since 2008. The Department completed a whole-stream nitrogen and phosphorus addition study between 2009 and 2011 (Montana Department Environmental Quality, 2009). Findings from that study are incorporated into this work as well. The Department also completed a mechanistic water quality model (QUAL2K) for the lower Yellowstone River and has recommended criteria for that waterbody using the model (Flynn and Suplee, 2011). Although the later work pertains to large rivers, findings from it help define the range of nutrient criteria one might expect for flowing waters of Montana.

Details on the specific literature that was most useful within each ecoregion will be provided in **Section 3.0.**

2.5.1 Literature Pertaining to Nutrient Enhancements in Rivers and Streams

Much of the scientific literature of the past few decades focuses on the effects of nitrogen (N) and phosphorus (P) over-enrichment. However, there is a smaller but equally valuable body of scientific literature addressing intentional nutrient *additions* to rivers and streams; these actions have usually been carried out for the purpose of enhancing depleted fisheries production (Holderman et al., 2009; Stockner, 2003). As we pointed out in Section 1.3 of Suplee et. al (2008), N and P have an interesting duality in that too much is a problem (cultural eutrophication), but too little can also be a problem (cultural oligotrophication).

Many of the nutrient-addition studies were carried out in the Pacific Northwest in streams and small rivers similar to those found in western Montana (Perrin et al., 1987; Johnston et al., 1990; KOHLER et al., 2008; Perrin and Richardson, 1997; Stockner and Shortreed, 1978). Because salmon die after spawning in the upper tributaries of rivers draining to the Pacific, large quantities of marine-sourced nutrients are relocated to the streams annually. But overfishing, dams, and habitat destruction have greatly reduced many salmon runs, leaving the streams stripped of their annual nutrient source. To boost survival of the few fry and fingerlings that are spawned, nutrient additions have been undertaken by resource managers. These nutrient additions enhance algal growth and secondary production (aquatic insects), which in turn provide a larger food source for the fish which enhances their growth and survival (Stockner and Ashley, 2003). This type of work has included large-scale nutrient additions to the Kootenai River as it flows out of Montana into Idaho. Ambient nutrients in the Kootenai River were greatly reduced after the completion of Libby dam in the early 1970s (Holderman et al., 2009).

The streams to which nutrients are added have very low ambient nutrient levels (ca. 5-10 µg TP/L and < 15 µg NO_3-N/L), and nutrient concentrations are only increased in the projects by a few additional micrograms per liter. These studies were very valuable in helping establish lower bounds for nutrient concentrations, below which it would usually not make sense to establish eutrophication-control criteria.

2.6 Both Nitrogen and Phosphorus Criteria are Recommended

The concept of nutrient limitation is important in the development of N and P criteria. Relative to N and P, limitation can be defined in a negative sense; a nutrient is *not* limiting if, when increased, one does not observe an effect on plant or algal growth (Gibson, 1971). The scientific literature has many examples of studies and analyses showing that N, or P, or commonly both stimulate algal production in surface waters (Francoeur, 2001; Smith et al., 1999; Tank and Dodds, 2003; Elser et al., 1990; Elser et al., 2007; Lewis et al., 2011). Co-limitation appears to be especially common in flowing waters , where nutrient-addition experiments show that added N and P result in much greater response of algal growth than does N- or P-addition alone (Elser et al., 2007). Regional work using nutrient diffusing substrates (N, P, and N+P) supports these findings (Mebane et al., 2009). Mebane et al.'s experiments were carried out *in situ* in intermontane wadeable streams of Idaho which are comparable to Montana's western streams. Background N and P concentrations in the streams ranged from very low (7 µg TP/L and 50 µg TN/L) to quite elevated (e.g., 91 µg TP/L and 1,820 µg TN/L). Based on the growth of algae on the nutrient diffusers that developed over 21 days, N and P co-limitation was indicated in three streams, N limitation was shown in two streams, and P limitation was found in one stream; one stream with highly elevated ambient nutrients showed no limitation (Mebane et al., 2009). And it should be noted, especially in light of the definition of nutrient limitation given above, that in most of the streams the greatest algal biomass developed on the N+P diffusers (Mebane et al., 2009).

Liebig's Law of the Minimum (Hooker, 1917) is a well established tenet in the agricultural sciences that states that biomass yield for a particular plant is usually limited by the nutrient that is present in the environment in the least quantity relative to the plant's need for that nutrient to support growth. The law is sometimes used to rationalize the idea that, in most cases, only P needs to be reduced to low concentrations to achieve eutrophication control in freshwaters. But Liebig's Law best applies to single plant species at a given place at a certain time, whereas the numeric nutrient criteria in this document apply to a mixed flora in flowing waters over several months of growing season. These flowing waters receive variable N and P loads over time and are home to mixed populations of algae species—and each species has somewhat different N and P requirements and capability of taking up nutrients (Hecky and Kilham, 1988; Borchardt, 1996). Streams are variable environments where, for example, N and P limitation can alternate as a function of stream discharge (Hullar and Vestal, 1989). Stated simply, limiting nutrient levels are not fixed. If for example P is presently limiting in a stream, that does not mean there is no point in limiting N. If P were to increase, say from summer rain events, or due to the confluence of a downstream tributary with slightly higher P concentrations, the N that was formerly in excess can become limiting without any change in its absolute concentration (Gibson, 1971). Similarly, a stream may be N-limited early in summer, and as surface flows drop, proportionally more N-rich groundwater enters the stream, shifting the stream to P-limitation. Results from twelve years of monitoring on the Clark Fork River in Montana support the idea that it is best to control both N and P.

There, in river locations where both the N standard and the P standard were met (20 µg TP/L and 300 µg TN/L), algal biomass has usually been reduced to the standard (150 mg Chl*a*/m^2). Locations in the river where these nutrient levels have not been met continue to have elevated algae, and study sites give mixed signals regarding nutrient limitation—some suggesting N limitation, others P; these signals are not consistent across time or location (Suplee et al., in press).

Water quality standards based on control of only a single nutrient (i.e., P) could result in unwanted ecological consequences in Montana's rivers and streams. Background nutrient levels in our western reference streams are usually quite low (10-18 µg TP/L and 85-190 µg TN/L; Smith et al., 2003; Suplee et al., 2007), and usually have TN:TP ratios at or somewhat higher than Redfield (Redfield = 7:1 by mass; Redfield, 1958). The nuisance diatom alga *Didymosphenia geminata* has, in recent years, spread to and formed nuisance benthic blooms in low-nutrient rivers and streams worldwide (Whitton et al., 2009; Kilroy, 2011; Spaulding and Elwell, 2007). It is found in Montana and, in western U.S. states, probabilistic survey data show that in over half of streams containing *D. geminata* TP is <10 µg/L (Spaulding and Elwell, 2007). Others also report that *D. geminata* usually occurs in streams with very low P (Whitton et al., 2009; Kilroy and Bothwell, 2012), and that it tends to disappear when TP exceeds about 20 µg/L (Lovstad, 2008). Further, *D. geminata* generally thrives in waters where N:P ratios are high (34:1 on average) much of the time (Whitton et al., 2009). *Didymosphenia geminata* blooms in low-P streams are caused by the diatoms' elevated production of polysaccharide stalks which develop as a consequence of phosphorus limitation (Kilroy, 2011; Kilroy and Bothwell, 2012). Stalk production in attached diatoms is considered competitively advantageous because it elevates the cells towards higher light (Hudon and Bourget, 1981), and this also places them in closer contact with available nutrients in flowing water (Kilroy and Bothwell, 2012)[4].

Researchers suggest that an effective way to diminish *D. geminata* blooms is to encourage its algal competitors by assuring that a sufficient (though small) supply of soluble phosphorus is available (Whitton et al., 2009; Kilroy and Bothwell, 2012). Indeed, the Montana Department of Fish, Wildlife and Parks is currently planning low-level phosphate addition experiments in troughs alongside the Kootenai River (where *D. geminata* blooms have become quite severe) to see if the alga can be brought under control via nutrient management actions. The alga is believed to be impacting the salmonid fishery there, where the high algal density appears to be reducing abundance of key aquatic insects which

[4] Alternative hypotheses exist regarding what controls *D. geminata* blooms in low-P streams. One of them states that the diatoms' polysaccharide stalks have an affinity for iron, which is absorbed to the stalks and in the process forms iron oxyhydroxide (Sundareshwar et al., 2011). Iron oxyhydroxides have a strong affinity for P and will adsorb (co-precipitate) it from the water (Mortimer, 1941; Caraco et al., 1989; Hasler and Einsele, 1948). Sundareshwar et al. (2011) posit that as the mat grows, anaerobic microbial decomposition (by iron- or sulfate-reducing bacteria) of dead diatoms within the mat leads to the reduction of the iron, formation of iron sulfides, and concomitant release of P. The abundant P is then available to the live diatoms at the mat surface, supporting further growth. The geochemical process they describe is well known in marine and freshwater systems (Suplee and Cotner, 2002). But the mechanism that Sundareshwar et al. (2011) propose is unsatisfactory, as it does not explain why the mats grow rapidly and develop to great size in low P streams in the first place. Sundareshwar et al. (2011) note that *D. geminata* produces high levels of alkaline phosphatase at the mat surface because the P sequestered there with iron is *not* bioavailable. Thus, we view their hypothesis as a potential mechanism for mat maintenance, but not necessarily for mat development. Others also find that this geochemical explanation does not jive with findings in *D. geminata* dominated streams, where increases in stream P concentrations lead to *declines* in *D. geminata* (Kilroy and Bothwell, 2012).

salmonids prey upon (Jim Dunnigan, Fishery Biologist, MT Fish Wildlife and Park, personal communication March 14, 2012).

Phosphorus reduction is often promoted as the only eutrophication control approach needed to control eutrophication, this being based largely on the more economical removal of P from wastewater (Lewis and Wurtsbaugh, 2008), and the assumption that P can be made to become limiting in the waterbody, *sensu* Liebig's Law. But the facts given above indicate that it would be unwise to recommend only P standards for control of excess algal biomass in our streams and rivers. A P-only approach, in order to work, would require that P standards be set to the background levels observed in our western region's reference sites (e.g., 10 µg TP/L). Total phosphorus concentrations this low are hard to achieve technologically, but if the P standard was not set to this low natural background, then the commonly occurring N-limitation or N and P co-limitation would lead to algal growth stimulation nonetheless. Worse yet, in the long term, a P-only strategy would result in highly skewed (elevated) N:P ratios accompanying the low P levels. These management-induced conditions might control green algae biomass but may lead to nuisance blooms of *D. geminata.*

A balanced and prudent policy would be to reduce both N and P and maintain, as nutrient concentration reductions occur, a roughly balanced (i.e., Redfield) ratio between the two. This is the strategy that has been applied on the Clark Fork River and it appears to be working (Suplee et al., in press). Other researchers in the field have recommended that both N and P need to be controlled to effectively manage eutrophication (Conley et al., 2009; Lewis et al., 2011; Paerl, 2009). Thus, we will generally be recommending both N and P criteria for wadeable streams and rivers in this document.

One final word on Redfield ratios. Studies of benthic algae show that it is necessary to move some distance above or below the Redfield ratio in order to be strongly convinced that a lotic waterbody is P or N limited (Dodds, 2003). When a benthic algal Redfield ratio (by mass) is <6, N limitation is suggested, and when it is >10 P limitation is indicated (Hillebrand and Sommer, 1999). Thus, there is a range of N:P values between about 6 and 10 where one can state, for practical purposes, that algal growth is co-limited by N and P.

3.0 ECOREGION-SPECIFIC NUMERIC NUTRIENT CRITERIA RECOMMENDATIONS

In this section are documented the numeric nutrient criteria for each ecoregion. Ecoregional information is arranged as follows: (1) first the level III ecoregion is presented, and (2) if any level IV ecoregions within the level III need to be treated separately, their information follows in a subsection. The same presentation format is followed for each ecoregion, be it level III or level IV, to the degree possible. Data specific to each ecoregion is presented on two to three pages. A map of Montana showing the ecoregion in which the criteria apply is shown first, followed by criteria recommendations and a table of descriptive statistics for the reference sites in the ecoregion. Then readers will find: histograms of the reference data TN and TP distributions (in cases where the data were skewed to the right they have been log_{10} transformed); a discussion of the scientific studies (regional and beyond) that were used to help derive the criteria, any other considerations pertaining to the derivation of the criteria; and a conclusion summarizing final thoughts on the criteria.

Data from reference sites (Suplee et al., 2005) were important in the process of deriving the nutrient criteria (see **Figure 1-2**). **Figure 3-1** below is a statewide map showing the locations of all stream reference sites current through August 2011. There are currently 185 different sites in the network.

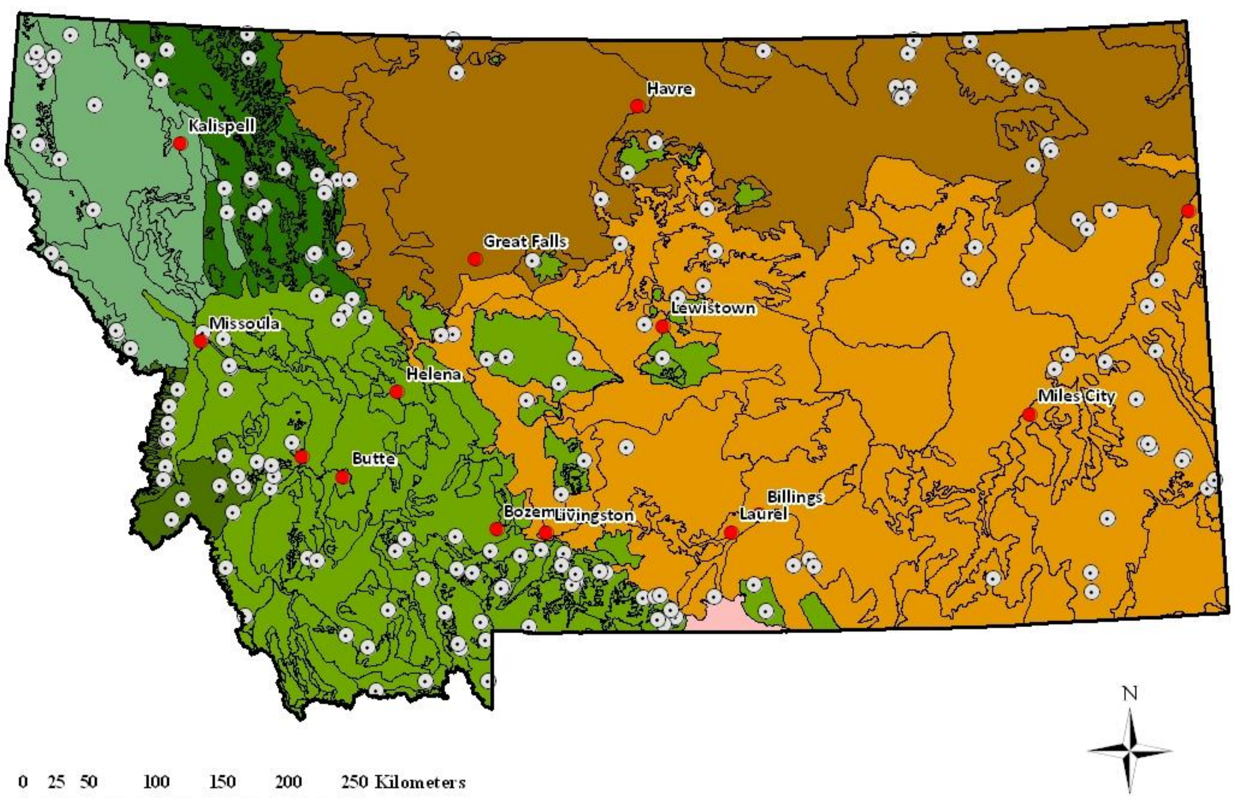


Figure 3-1. Map of Montana showing location of stream references sites (white dots). Colored regions denote level III ecoregions. Red dots show the major towns.

3.1 Level III: Middle Rockies (Ecoregion 17)

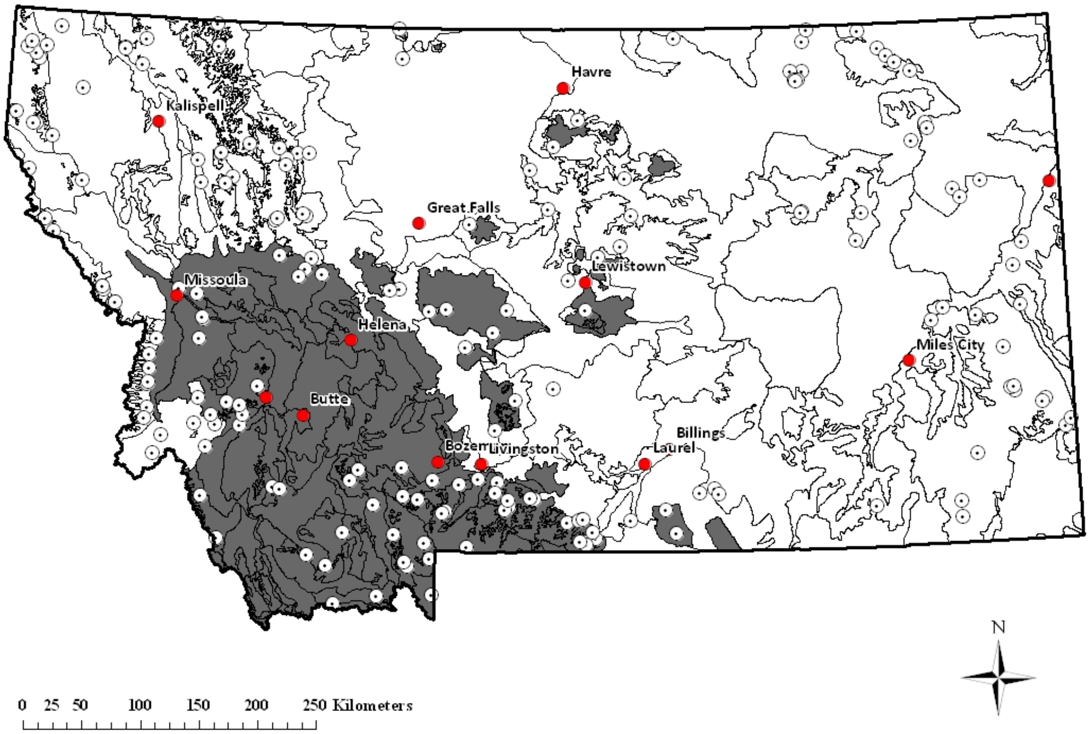


Figure 3-2. Map of Montana showing the Middle Rockies ecoregion in gray.
White dots are the reference sites.

Recommended Numeric Criteria
Total Phosphorus: **30 µg TP/L**
Total Nitrogen: **300 µg TN/L**

N:P Ratio of Criteria: **10:1**
N:P Ratio of Reference Sites: **10:1** (Redfield N:P ratio = 7:1)

Descriptive Statistics of Regional Reference Sites

Table 3-1. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Middle Rockies ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	57	148	3	9580	55	95	141	220
TP	61	245	0.5	840	6	10	20	70

The 30 µg TP/L criterion matches to the 80th percentile of reference.
The 300 µg TN/L criterion matches to the 93th percentile of reference.

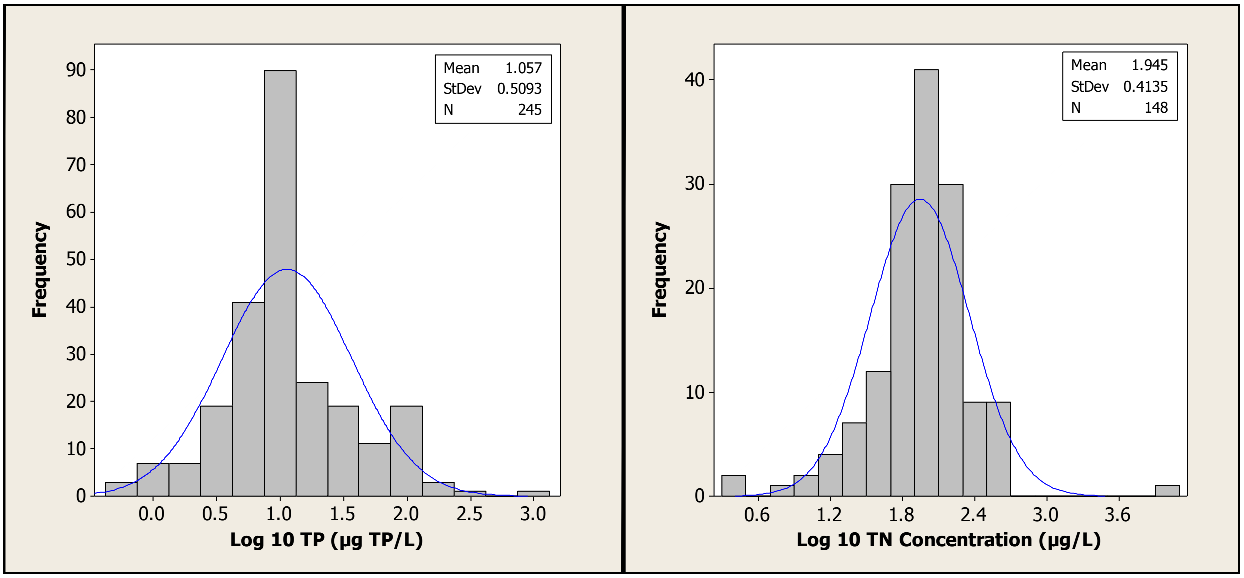


Figure 3-3. Nutrient concentrations from reference streams in the Middle Rockies ecoregion. Data were collected during the Growing Season (July 1-September 30).

Discussion of the Middle Rockies Ecoregion Nutrient Criteria

Two regional dose-response studies were available that relate TN and TP to stream impacts (Mebane et al., 2009; Suplee et al., in press). Suplee et al. (in press) show that TP is saturated in the Clark Fork River at 24 µg/L. They also suggest that criteria for the Clark Fork River— upstream of the Flathead River confluence— be set uniformly to about 20 µg TP/L and 300 µg TN/L to meet the algae standard (150 mg Chl*a*/m^2 max). Further, they indicate that both TN and TP criteria should be met to achieve the intended reductions in algal biomass. Suplee et al. build on earlier work in which nutrient criteria were developed for the Clark Fork River(Dodds et al., 1997), and by doing so provide large-scale confirmation that the original criteria were largely correct. Mebane et al. (2009) carried out a study in southern Idaho. Many of the streams were intermontane and, thus, very similar to intermontane streams of this ecoregion. They recommend 40 µg TP/L and 600 µg TN/L in order to maintain benthic algae growth ≤150 mg Chl*a*/m^2, per Suplee et al. (2009). To maintain 125 mg Chl*a*/m^2, which is generally appropriate for shallow wadeable streams[5], the values would drop to about 35 µg TP/L and 475 µg TN/L.

Beyond the Middle Rockies ecoregion, studies in northern and southern temperate rivers and streams show that nutrient-benthic Chl*a* regressions have breakpoints at 27-62 µg/L for TP and between 367-602 µg/L for TN (Dodds et al., 2006; Dodds et al., 2002). What this indicates is that above the breakpoint

[5] A nutrient dose-response study carried out by the Department in southeastern Montana showed that in a wadeable stream benthic algae levels of 127 mg Chl*a*/m^2 (33 g AFDM/m^2) led to seasonal exceedances of the dissolved oxygen (DO) standard (Suplee and Sada de Suplee, 2011). Subsequent work—using a model based on Streeter-Phelps (1925) and cooler water temperatures more typical of mountainous streams—showed that DO exceedances would still occur in many western MT streams. Therefore, when using Chl*a*-nutrient relationships from Mebane et al. (2009), Dodds et al. (1997; 2006), and others, we used 125 mg Chl*a*/m^2 as the target algae level. The Department believes this value is a well-supported threshold, giving consideration to both the DO impacts observed in the dosing study and also the recreational threshold (and regarding the later, giving consideration to the known statistical patterns of the Department's SOP Chl*a* method). We continue to also use 150 mg Chl*a*/m^2 as well, which is the arithmetic mean of the replicates for the highest level of benthic algae found to be acceptable to the MT public (Suplee et al., 2009).

concentrations, nutrients are saturated, and benthic algae control via nutrient control become ineffective. Stevenson et al. (2006) show in Michigan streams that the likelihood of reaching bottom coverage by *Cladophor*a of 20-40% increases sharply when TP exceed 30 µg/L, and TN exceeds 1,000 µg/L. This level of streambed coverage by *Cladophora* was found to be unacceptable to the Montana public (see Suplee et al., 2009, Table 1). Chambers et al. (2011) derive nutrient criteria for Canadian streams using multiple methods including dose-response relationships between nutrients and algae and macroinvertebrate metrics. They recommend 20 µg TP/L and 210 µg TN/L for the Montane Cordillera, a mountainous region in British Columbia (in fact, part of the Northern Rockies ecoregion). Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19), were used to calculate TN levels that would maintain 125 mg Chl*a*/m^2 benthic algae given a TP of 30 µg TP/L. These equations resulted in TN concentrations ranging from 466-718 µg TN/L. If the algae level is set instead to 150 mg Chl*a*/m^2, and 30 µg TP/L is again used, the TN values range from 750 to 1,210 µg/L.

Conclusion

Studies that have the most specificity to the Middle Rockies suggest criteria ranging from 20-40 µg TP/L and 300-600 µg TN/L. Studies further afield provide a range of criteria to prevent nuisance algal growth or impacts to aquatic life communities ranging from 20-30 µg TP/L and 210-1,210 µg TN/L. **We recommend for this ecoregion 30 µg TP/L and 300 µg TN/L**. We recommend these values because: (1) these concentrations fall within the ranges provided in the studies, especially studies that are most pertinent to the ecoregion; (2) they maintain an N:P ratio of 10 which matches the natural condition of regional reference sites (i.e., 9.5:1) and is fairly close to Redfield (therefore indicating no definitive N or P limitation); and (3) they should generally encourage a balanced and diverse stream flora for this region by keeping nutrient ratios near Redfield and TP at a concentration which will help inhibit *Didymosphenia geminata* blooms.

3.1.1 Level IV Ecoregion within the Middle Rockies: Absaroka-Gallatin Volcanic Mountains (17i)

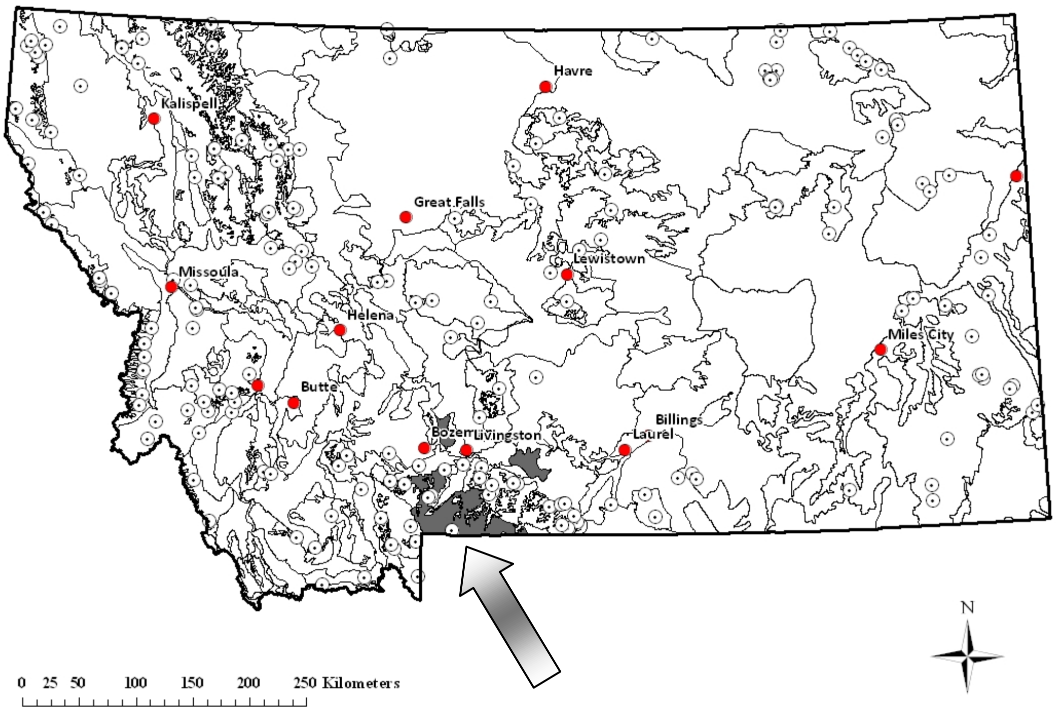


Figure 3-4. Map of Montana showing the Absaroka-Gallatin volcanic Mountains (17i), a level IV ecoregion within the Middle Rockies ecoregion.
White dots are the reference sites.

Recommended Numeric Criteria
Total Phosphorus: **105 µg TP/L**
Total Nitrogen: **250 µg TN/L**

N:P Ratio of Criteria: **2:1**
N:P Ratio of Reference Sites: **1:1** (Redfield N:P ratio = 7:1)

Descriptive Statistics of Regional Reference Sites

Table 3-2. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Absaroka-Gallatin Volcanic Mountains (17i) ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	4	13	7	181	52	80	100	163
TP	4	16	16	144	61	81	105	127

The 105 µg TP/L criterion matches to the 75th percentile of reference.
The 250 µg TN/L criterion is greater than the 100th percentile of reference.

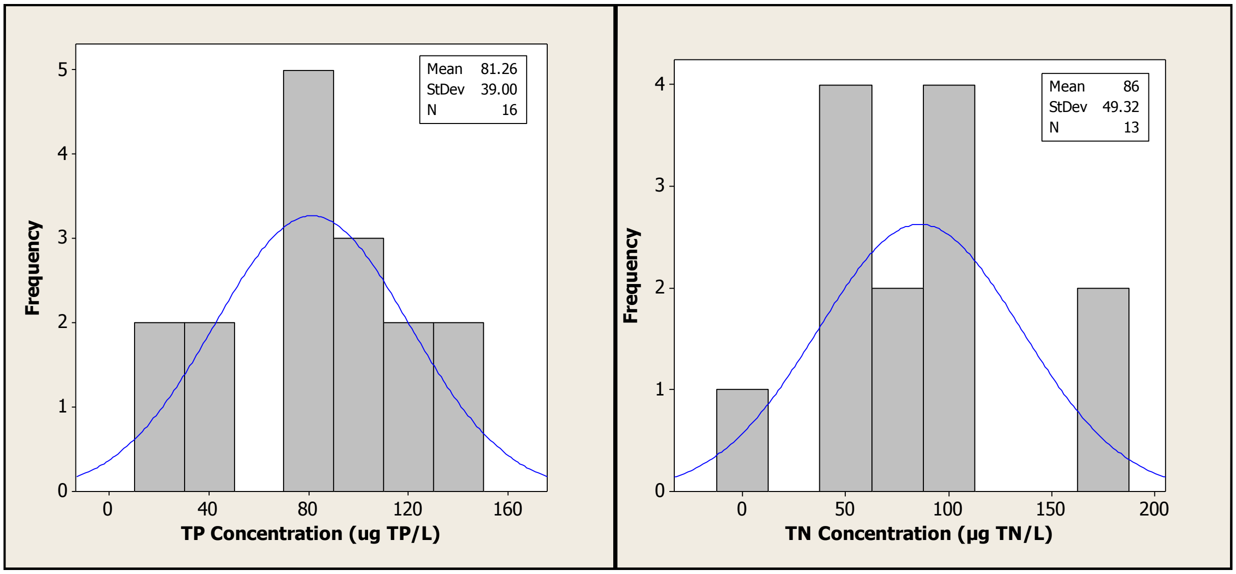


Figure 3-5. Nutrient concentrations from reference streams in the Absaroka-Gallatin Volcanic Mountains (17i) ecoregion.
Data are from the Growing Season (July 1-September 30).

Discussion of the Absaroka-Gallatin Volcanic Mountains Ecoregion
The Absaroka-Gallatin Volcanic Mountains ecoregion (17i) has statistically significantly higher TP concentrations than the rest of the Middle Rockies (Varghese and Cleland, 2008; Varghese and Cleland, 2009). Permian age Phosphoria formations (United States Geological Survey, 1951) outcrop throughout this ecoregion and cause naturally elevated P concentrations. The natural concentrations of TP in 17i exceed harm-to-use thresholds identified for the Middle Rockies (20-40 µg TP/L). The median TP concentration of reference streams in ecoregion 17i is 81 µg/L, compared to 10 µg/L for the Middle Rockies as a whole, and is therefore already higher than saturation (Dodds et al., 2006).

Observation of the reference streams of this ecoregion indicate that nuisance levels of benthic algae are not developing. This suggests that they are N limited, otherwise one would expect high algae levels at these TP concentrations (as observed in the transitional level IV ecoregions of the Northwestern Glaciated Plains, discussed later on). Natural TN levels in these streams are fairly low, lower than what is observed in the Middle Rockies as a whole. To assure that management-induced changes in TN do not lead to stream impacts, careful consideration of the appropriate TN criterion was essential. Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate TN that would maintain 125 mg Chl*a*/m^2 benthic algae given a TP of 105 µg/L (105 µg TP/L = 75th percentile of reference of 17i). This resulted in TN concentrations from 245 to 287 µg TN/L. If the algae level is set instead to 150 mg Chl*a*/m^2, and 105 µg TP/L is again used, the TN values range from 322 to 483 µg/L. Total phosphorus at the 75th percentile of reference was selected because it assures that the majority of data from the ecoregion's reference sites are below the TP criteria, and it lends itself well to reach-specific criteria derivation in cases where a stream reach further down gradient receives water from both the Middle Rockies and the Absaroka-Gallatin Volcanic Mountains (more on this in **Section 4.2**).

<u>**Conclusion**</u>
We recommend 105 µg TP/L and 250 µg TN/L as criteria for this level IV ecoregion. The TN criterion is somewhat more restrictive here than the 300 µg/L recommended for the Middle Rockies; this is to

assure adequate control of N in these apparently N-limited streams. The criteria have an N:P ratio of 2:1, however this is acceptable because maintaining a ratio near to Redfield is not realistic (or necessary) since the streams' natural N:P ratios are already skewed low (on the order of 1:1). The reference data for this ecoregion were collected between 1990 and 2009, providing good temporal dispersion. Since there are still only a minimal number of samples (13-16) available for characterizing this ecoregion we recommend continued sample collection to increase the sample size.

3.2 Level III: Northern Rockies (Ecoregion 15)

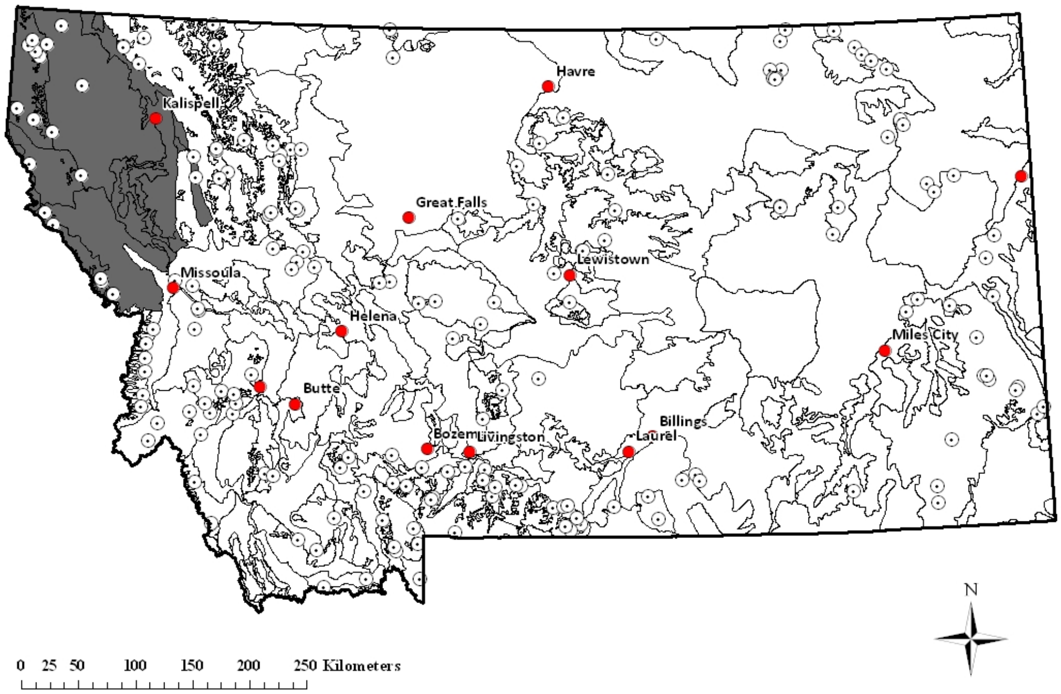


Figure 3-6. Map of Montana showing Northern Rockies ecoregion. White dots are the reference sites.

<u>Recommended Numeric Criteria</u>
Total Phosphorus: **30 µg TP/L**
Total Nitrogen: **300 µg TN/L**

N:P Ratio of Criteria: **10:1**
N:P Ratio of Reference Sites: **7:1** (Redfield N:P ratio = 7:1)

<u>Descriptive Statistics of Regional Reference Sites</u>

Table 3-3. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Northern Rockies ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	22	76	3	360	18	41	94	167
TP	22	81	0.5	18	4	6	9	13

The 30 µg TP/L criterion is greater than the 100th percentile of reference.
The 300 µg TN/L criterion matches to the 97th percentile of reference.

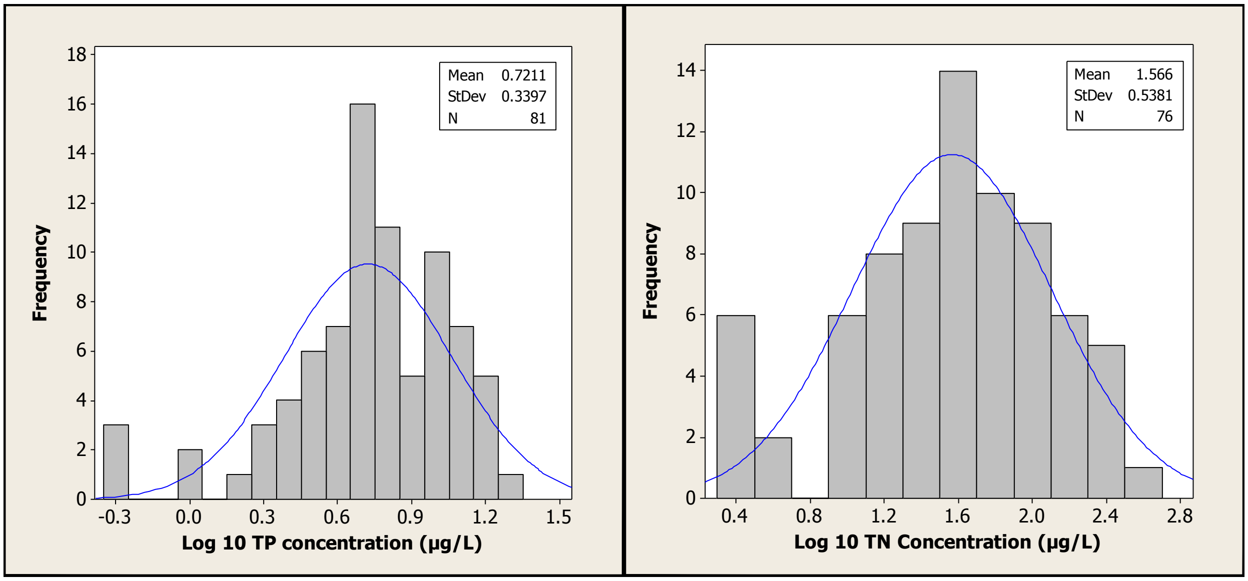


Figure 3-7. Nutrient concentrations from reference streams in the Northern Rockies ecoregion. Data were collected during the Growing Season (July 1-September 30).

<u>Discussion of the Northern Rockies Ecoregion Nutrient Criteria</u>

Three regional dose-response studies specific to the Northern Rockies were available that relate nutrients (both soluble and total forms) to stream impacts or changes in aquatic communities. Welch et al. (1989) use a model and an artificial stream study and then adapt them to an open river system (Spokane River, Washington). Their equations indicate that at 10 µg soluble reactive phosphate (SRP)/L, the distance on the river with algal biomass of 150 mg Chl*a*/m^2 would be constrained to 16 km. The Montana public found a mean of ≤150 mg Chl*a*/m^2 acceptable for river recreation[6]. Assuming an SRP:TP ratio of 0.25:1 (as is commonly observed on the Clark Fork River), 10 µg SRP/L equals 40 µg TP/L. Chambers et al. (2011) derive nutrient criteria for Canadian streams using multiple methods including dose-response relationships between nutrients and algae and macroinvertebrate metrics. The study streams were located in the Okanagan Basin (British Columbia) just north of Washington State, and are within the Northern Rockies ecoregion. They recommend 20 µg TP/L and 210 µg TN/L for streams of the region to protect aquatic life.

The third study (Gravelle et al., 2009a; Gravelle et al., 2009b) discusses a Before After Control Impact Paired study in which the authors assess the effects of different timber harvest intensities on nutrient concentrations and aquatic insect metrics in the Mica Creek Experimental Watershed in northern Idaho. In the post-road construction period (1998-2001), summer TP increased to about 40 µg/L, TKN increased slightly to about 150 µg/L, and nitrate+nitrite did not change. Later, in the post-harvest period (2002-2006), TP declined again to 20 µg/L and TKN to about 40 µg/L, but nitrate+nitrite increased markedly to a monthly summer average of 350 µg/L (about 400 µg TN/L). Across this entire ten year period there were very few changes in the aquatic insect metrics monitored, although Ephemeroptera, Plecoptera, and Trichoptera abundance increased over the period (Gravelle et al., 2009b). Among the biometrics,

[6] The Spokane River is a 6th order river and is therefore on the large side of wadeable (Flynn and Suplee, 2010), and impacts to dissolved oxygen standards would be less likely in a river this size due to good re-aeration and total river volume. Therefore we only used 150 mg Chl*a*/m^2 in the equation (as opposed to 125 mg Chl*a*/m^2, discussed in **footnote 5**).

the Hilsenhoff Biotic Metric (HBI) was of particular interest as the Department uses it as part of the assessment of nutrient impacts in mountainous streams (Suplee and Sada de Suplee, 2011). Relative to the control period (1994-1997), HBI scores were essentially unaffected by the nutrient concentration changes observed. Based on the data, it is likely that the streams were N limited in the post-road period and P limited in the post-harvest period.

Beyond this ecoregion, applicable studies are essentially the same as described in **Section 3-1** for the Middle Rockies (excluding Chambers et al., 2011). These studies indicate a range of candidate criteria from 20-30 µg TP/L and 300-1,210 µg TN/L. Work by Mebane et al. (2009) in central Idaho has less direct application here, but note that streams where they observed very low ambient TP and TN concentrations (similar in concentration to Northern Rockies reference streams) N and P co-limitation was the norm.

Conclusion

We recommend 30 µg TP/L and 300 µg TN/L for this ecoregion. The scientific literature most specific to this ecoregion (Welch et al., 1989; Chambers et al., 2011; Gravelle et al., 2009a; Gravelle et al., 2009b) suggests criteria ranging from 20-40 µg TP/L and 210-400 µg TN/L. The concentrations 30 µg TP/L and 300 µg TN/L result in an N:P ratio of 10, which is higher than the regional reference stream ratio (7:1) but still within the Redfield range where co-limitation by N and P is likely.

3.3 Level III: Canadian Rockies (Ecoregion 41)

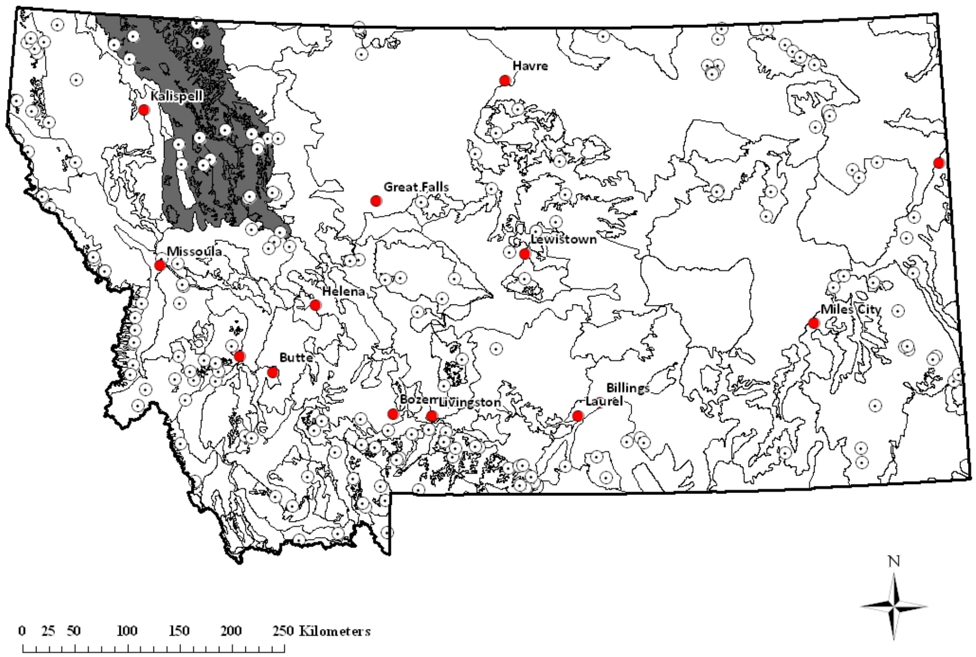


Figure 3-8. Map of Montana showing Canadian Rockies ecoregion.
White dots are the reference sites.

Recommended Numeric Criteria
Total Phosphorus: **25µg TP/L**
Total Nitrogen: **350 µg TN/L**

N:P Ratio of Criteria: **14:1**
N:P Ratio of Reference Sites: **16:1** (Redfield N:P ratio = 7:1)

Descriptive Statistics of Regional Reference Sites

Table 3-4. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Canadian Rockies ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	Number of Reference Sites	Number of Samples	Min	Max	25th	(Median)50th	75th	90th
TN	13	39	2.5	413	27	63	156	268
TP	14	48	0.5	35	2	4	6	9

The 25 µg TP/L criterion is matches to the 97th percentile of reference.
The 350 µg TN/L criterion matches to the 98th percentile of reference.

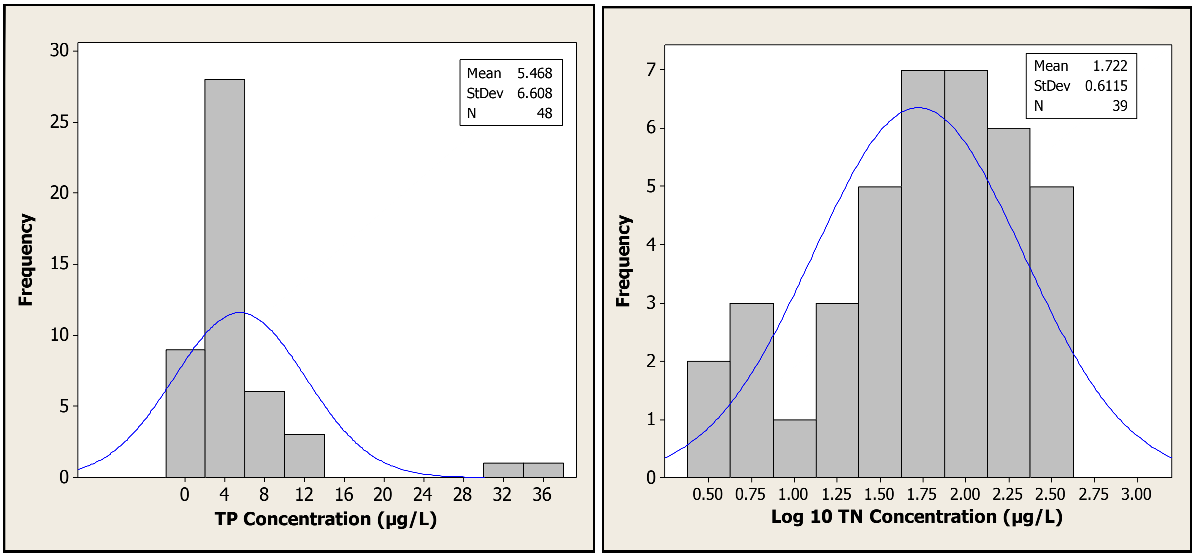


Figure 3-9. Nutrient concentrations from reference streams in the Canadian Rockies ecoregion. Data were collected during the Growing Season (July 1-September 30).

Discussion of the Canadian Rockies Ecoregion Nutrient Criteria

Several studies have direct application to the Canadian Rockies (Sosiak, 2002; Bowman et al., 2007; Scrimgeour and Chambers, 2000). All three were carried out in Canadian rivers in the ecoregion. No model equation between benthic Chl*a* and nutrients was provided in Bowman et al. (2007), however Michelle Bowman graciously provided us the data for the relationship between TP and benthic Chl*a* from their study (personal communication, January 21, 2009). The TP-Chl*a* correlation, though weak, suggests that benthic algal biomass of 150 mg Chl*a*/m^2 equates to 89 µg TP/L, and 125 mg Chl*a*/m^2 equates to 66 µg TP/L (see **footnote 5** for information pertaining to the benthic algae levels used here).

Sosiak (2002) provides a Chl*a* vs. total dissolved phosphate (TDP) + NO_{2+3} multiple-regression equation, and a conversion between TDP and TP concentrations for the Bow River (TP is about 2.8 X TDP). He reports that 150 mg Chl*a*/m^2 equates to 18 µg TP/L (equal to 10 µg TP/L @ 125 mg Chl*a*/m^2). But he assumes that nitrate in the river is essentially saturated (conc. = 267 µg NO_{2+3}-N/L). We reset the NO_{2+3} in the equation to a value (50 µg NO_{2+3}-N/L) that is a much more realistic proportion of any foreseeable TN criterion, with the following results: 150 mg Chl*a*/m^2 corresponds to 41 µg TP/L, and 125 mg Chl*a*/m^2 equates to 23 µg TP/L. Scrimgeour and Chambers (2000) note that, in the absence of human influence, the Wapiti-Smokey rivers are probably P limited, but once alterations to the water quality occur due to kraft mill effluent, N and P co-limitation is most common. Finally, watershed managers on the Bow River are recommending 28 µg TP/L in the central Bow River in order to maintain benthic algae ≤ 150 mg Chl*a*/m^2 (Bow River Basin Council, 2008).

Relevant dose-response studies from outside the ecoregion are essentially the same as those described for the Middle Rockies. Work carried out in northern and southern temperate rivers and streams show that nutrient-benthic Chl*a* regressions have breakpoints at 27-62 µg/L for TP and between 367-602 µg/L for TN (Dodds et al., 2006). Stevenson et al. (2006) show in Michigan streams that the likelihood of reaching bottom coverage by *Cladophor*a of 20-40% increases sharply when TP exceed 30 µg TP/L and 1,000 µg TN/L. This level of streambed coverage by *Cladophora* is unacceptable to the Montana public (see Suplee et al., 2009, Table 1). Chambers et al. (2011) derive nutrient criteria for Canadian streams using multiple methods including dose-response relationships between nutrients and algae and macroinvertebrate metrics. They recommend 20 µg TP/L and 210 µg TN/L for the Montane Cordillera, a mountainous region west and north of Montana in British Columbia (in the Northern Rockies ecoregion). Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19, respectively), were used to calculate TN levels that would maintain 125 mg Chl*a*/m^2 given a TP of 25 µg/L. These equations result in TN concentrations ranging from 528-821 µg TN/L. But Bowman et al. (2007) state that nutrient-algae relationships in nutrient-poor lotic systems are harder to predict, and specifically note that Dodds' equations under predict benthic algal biomass of oligotrophic rivers such as those found in the Canadian Rockies. As such, Dodds' equations (and the work of Stevenson et al. (2006)) need to be considered cautiously in this ecoregion.

Conclusion

Total P values derived from Sosiak (2002) and Bowman et al. (Bowman et al., 2007) are in the range of 23 to 89 µg TP/L. The Bow River Basin Council (2008) suggests 28 µg TP/L to maintain river benthic algae at the same levels considered here. None of the equations specific to the Canadian Rockies provide a means to easily derive a TN criterion. Given that the reference sites in this ecoregion have a fairly high TN:TP ratio (16:1, **Table 3-4**; highest of the western ecoregions), and that others have noted the inherent P limitation of the region (Scrimgeour and Chambers, 2000), it would be prudent to establish TP values that maintain this inherent P limitation. **We recommend 25 µg TP/L, and a corresponding TN criterion (giving consideration to Redfield and the region's natural N:P ratio) of 350 µg TN/L.** Criteria in this ratio (14:1) should induce slight P limitation (as is inherent in the ecoregion), but are shifted somewhat toward a Redfield ratio that would result in co-limitation.

A final note. One level IV ecoregion within the Canadian Rockies, the Southern Carbonate Front (41d), had statistically higher total Kjeldahl N (TKN) concentrations in its reference sites compared to reference sites of the rest of the Canadian Rockies (Varghese and Cleland, 2008; Varghese and Cleland, 2009). Total Kjeldahl N is a close surrogate for TN, therefore we investigated whether or not this level IV ecoregion should have a separate TN criterion. Although the Southern Carbonate Front's median TN concentration (73 µg TN/L) is higher than the Canadian Rockies as a whole (63 µg TN/L; **Table 3-4**), the Southern Carbonate Front's nitrogen levels are not high enough to warrant separate criteria. The criterion recommended for the Canadian Rockies, 350 µg TN/L, matched the 93rd percentile of the Southern Carbonate Front's TN and TKN reference distribution. (When only its TN data were considered, 350 µg TN/L matched the 95th.) Thus, 350 µg TN/L is a realistic and achievable criterion for this level IV ecoregion as well.

3.4 Level III: Idaho Batholith (Ecoregion 16)

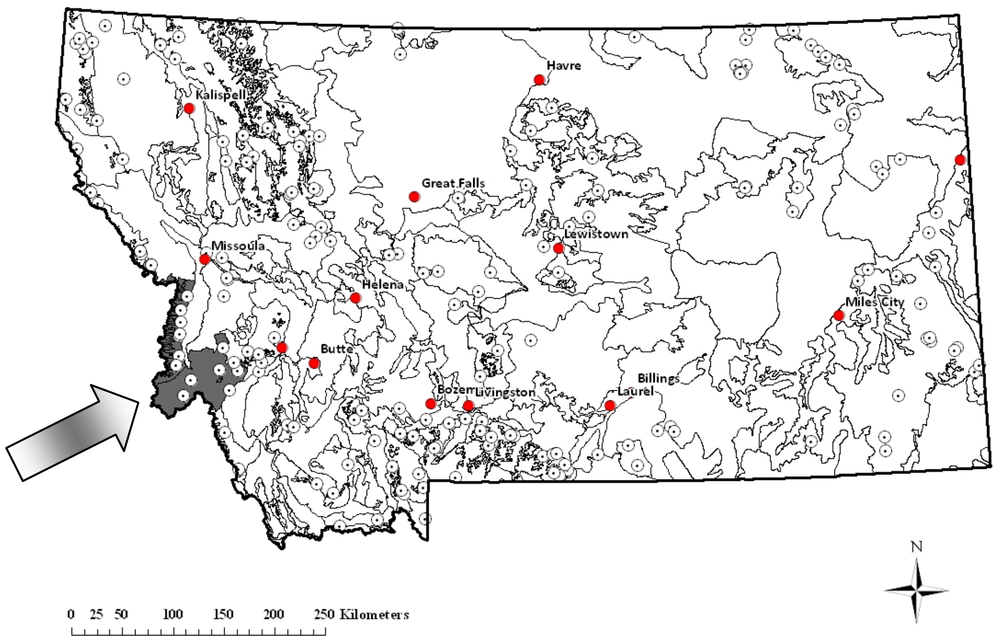


Figure 3-10. Map of Montana showing the Idaho Batholith ecoregion.
White dots are the reference sites.

Recommended Numeric Criteria
Total Phosphorus: **30 µg TP/L**
Total Nitrogen: **300 µg TN/L**

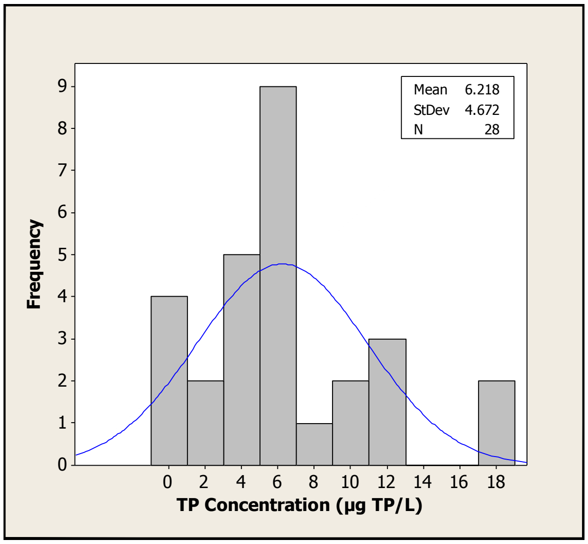
N:P Ratio of Criteria: **12:1**
N:P Ratio of Reference Sites: **12:1** (Redfield N:P ratio = 7:1)

Descriptive Statistics of Regional Reference Sites

Table 3-5. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Idaho Batholith ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25^{th}**	**(Median)50^{th}**	**75^{th}**	**90^{th}**
TN	9	28	2.5	238	46	70	95	163
TP	9	28	0.5	19	4	6	8	11

The 30 µg TP/L criterion is beyond the 100^{th} percentile of reference.
The 300 µg TN/L criterion is beyond the 100^{th} percentile of reference.



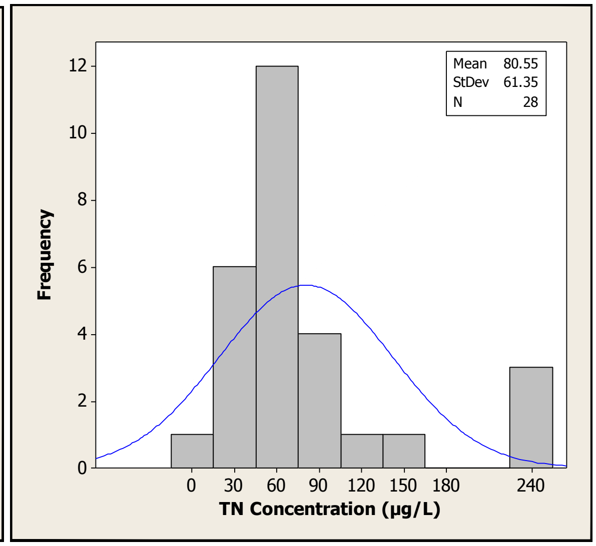


Figure 3-11. Nutrient concentrations from reference streams in the Idaho Batholith ecoregion. Data were collected during the Growing Season (July 1-September 30).

<u>**Discussion of the Idaho Batholith Ecoregion Nutrient Criteria**</u>

There is a relatively small extent of this level III ecoregion in Montana (most of it is found in central Idaho). Mebane et al. (2009) carried out a multiple approach, dose-response study in wadeable streams, and several of their sites are located in the Idaho Batholith ecoregion of central Idaho. They carried out *in situ* nutrient limitation trials using nutrient diffusers and other approaches. One of their study sites located in the Idaho Batholith (the Big Wood River) had very low ambient nutrients (7-10 µg TN/L and 50-150 µg TN/L), not unlike reference streams of this ecoregion in Montana (**Table 3-5; Figure 3-11**). The Big Wood River was found to be very strongly N and P co-limited and, in fact, single N- and P-additions alone grew no more algae than did the un-amended control. This indicates that N or P alone (no control on the other) would need to be maintained at concentrations no higher than natural background (ca. 8 µg TP/L or 100 µg TN/L) to prevent substantial increases in benthic algal growth. Among the study streams, N and P co-limitation or N-limitation was most common. These data demonstrate that coupled N and P criteria are important to maintain desired water quality conditions. Mebane et al. (2009) recommend criteria of 40 µg TP/L and 600 µg TN/L in order to maintain benthic algae growth to ≤150 mg Chl*a*/m^2, per Suplee et al. (2009). But to maintain 125 mg Chl*a*/m^2, which is more appropriate for many wadeable streams (see **footnote 5**), corresponding concentrations are about 35 µg TP/L and 475 µg TN/L. Note that in Mebane et al.'s study a good response curve was obtained between benthic algal Chl*a* and TN. This was less true for TP where, in a number of cases, there were a fair number of observations falling outside the Chl*a*-TP response curve (i.e., higher benthic algal Chl*a* was observed at lower-than-predicted TP levels). Finally, the study of Mebane et al. (2009) included a number of sites in agricultural settings of the Snake River Plain ecoregion (12), so the study's findings should only be carried so far when applying them to the Idaho Batholith.

Relevant dose-response studies from outside the ecoregion would be the same as those described for the Northern Rockies and Canadian Rockies, which have similar nutrient concentrations. Chambers et al. (2011) derive nutrient criteria for Canadian streams using multiple methods, including dose-response of nutrients vs. algae and macroinvertebrate metrics. They recommend 20 µg TP/L and 210 µg TN/L for the Montane Cordillera, a mountainous region in the Northern Rockies ecoregion. Other work in the Northern Rockies suggests values of about 40 µg TP/L and 400 µg TN/L (Gravelle et al., 2009a; Gravelle et al., 2009b). In the Canadian Rockies, a TP criterion could fall between 23 and 89 µg/L and, for the Bow

River there, we documented a recommendation of 28 µg TP/L (Bow River Basin Council, 2008). Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate TN levels that would maintain 125 mg Chl*a*/m^2 benthic algae, given a TP of 30 µg TP/L. These equations resulted in TN concentrations from 466-718 µg TN/L. But Bowman et al. (2007) note that nutrient-algae relationships in nutrient-poor lotic systems (like the Idaho Batholith) are harder to predict and, specifically, the equations of Dodds et al. (2006) under predict the actual benthic algal growth observed.

<u>**Conclusion**</u>

We found that a study that has application to this ecoregion (Mebane et al., 2009) indicates strong N and P co-limitation or N-limitation in the ecoregion's streams, apparently due to very low natural background nutrient concentrations. These low background nutrient concentrations are similar to those observed in the Northern and Canadian Rockies ecoregions (**Tables 3-3, 3-4**). The work of Mebane et al. (2009) suggests that good control of nitrogen is probably of greater importance in controlling algal biomass than phosphorus. Bowman et al. (2007) state that nutrient-algae relationships in nutrient-poor lotic systems are hard to predict, and that published models (such as Dodds et al., 2006) under predict actual benthic algal biomass. We gave this finding careful consideration when we evaluated the range of potential criteria for this ecoregion. The work of Mebane et al. (2009) suggests values of 35-40 µg TP/L and 475-600 µg TN/L. Taken together with the broader range of recommended values that are most applicable to the Idaho Batholith (20-89 µg TP/L and 210-400 µg TN/L), **we recommend 30 µg TP/L and 300 µg TN/L.** The TN and TP criteria we recommend are in a ratio (10:1) that is fairly close to the natural background for the Idaho Batholith (12:1; **Table 3-5**) and which (based on Redfield) would result in N and P co-limitation.

3.5 LEVEL III: NORTHWESTERN GLACIATED PLAINS (ECOREGION 42)

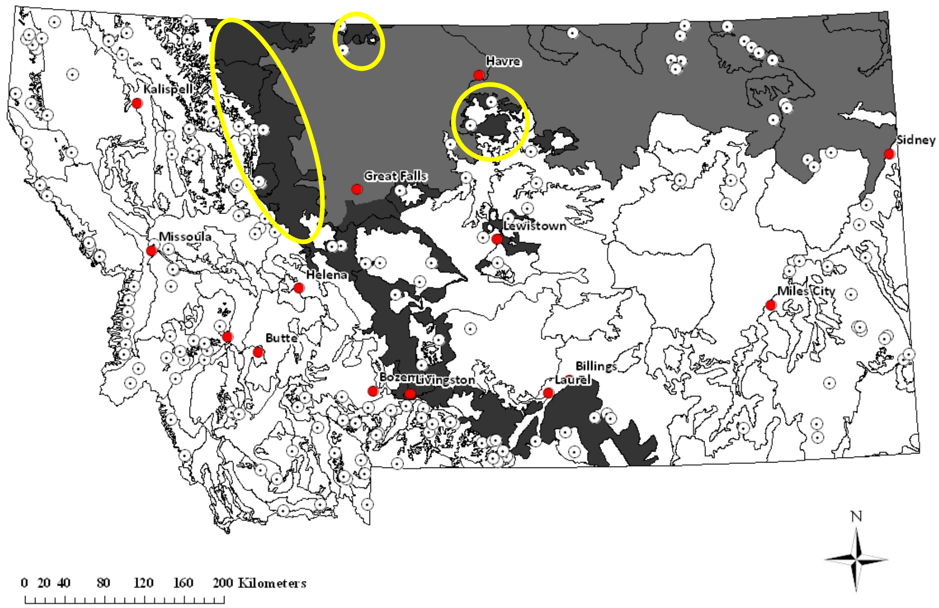


Figure 3-12. Map of Montana showing the Northwestern Glaciated Plains ecoregion (42) in light gray. The dark gray area is a mountain-to-plains transitional zone comprised of level IV ecoregions within ecoregion 42 (and 43, to the south). Mountain-to-plains transitional level IVs that are part of the Northwestern Glaciated Plains (circled in yellow) were not included among the reference data compiled here. White dots are the reference sites.

<u>Recommended Numeric Criteria</u>

Total Phosphorus: **110 µg TP/L**
Total Nitrogen: **1,400 µg TN/L**

N:P Ratio of Criteria: **13:1**
N:P Ratio of Reference Sites: **16:1** (Redfield N:P ratio = 7:1)

<u>Descriptive Statistics of Regional Reference Sites</u>

Table 3-6. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Northwestern Glaciated Plains ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	17	52	55	3891	630	969	1398	1945
TP	18	59	10	638	28	60	111	184

The 110 µg TP/L criterion matches to the 75th percentile of reference.
The 1,400 µg TN/L criterion matches to the 75th percentile of reference.

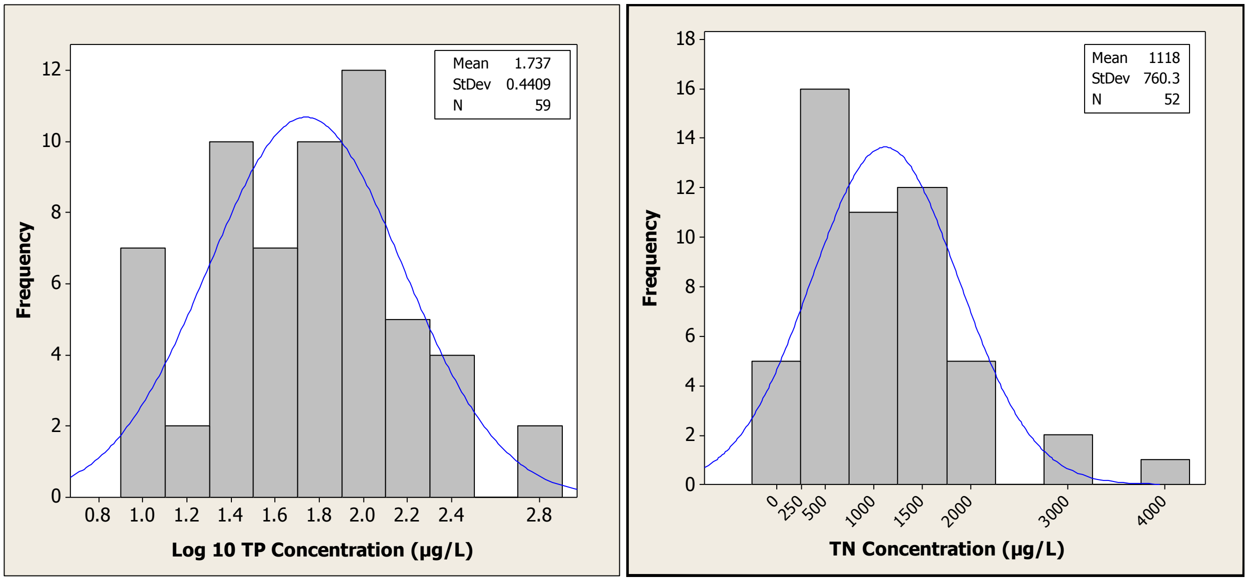


Figure 3-13. Nutrient concentrations from reference streams in the Northwestern Glaciated Plains ecoregion, but excluding data from the level IV ecoregions 42l, 42n, 42q, and 42r.
Data were collected during the Growing Season (June 16-September 30).

<u>Discussion of the Northwestern Glaciated Plains Nutrient Criteria</u>
One study has direct application to the Northwestern Glaciated Plains (Suplee et al., 2008), and there are three additional studies carried out in this ecoregion or in glaciated plains regions further east that have relevance (Wang et al., 2007; Heiskary et al., 2010; Chambers et al., 2011). In appendix A of the report to which this addendum is attached (Suplee et al., 2008), a relationship is shown between TN concentrations and dissolved oxygen (DO) concentrations as inferred by diatom taxa. Once TN was higher than 1,120 µg TN/L, streams sites had DO concentrations lower than the B-2 DO standard (5.0 mg/L; DEQ, 2010); B-2 streams are widespread throughout this ecoregion. Note in **Table 3-6** above that this threshold concentration (1,120 µg TN/L) matches the 60th percentile of reference; rather low in the reference distribution given that reference sites—by definition— are minimally impacted and support their uses. On close observation of Figure 3.2 in Appendix A of (Suplee et al., 2008), it appears that a concentration between 1,100 and 1,450 µg TN/L could be appropriate as a threshold. Indeed, the 90% confidence interval around the threshold is 780 to 1,480 mg TN/L (Suplee et al., 2008). Giving consideration to the ecoregion's reference distribution (**Table 3-6**), where the 75th percentile of reference equals 1,400 µg TN/L, a TN criterion of 1,400 µg TN/L appears to be appropriate. It should also be noted that N limitation was strongly indicated in wadeable streams of this region (Suplee, 2004). Although the TN:TP ratio of the reference sites (16:1) might suggest the contrary, Redfield ratios are only meaningful when nutrient concentrations are low (much lower than the natural concentrations found in this ecoregion).

Chambers et al. (2011) derive nutrient criteria for prairie streams of the Northwestern Glaciated Plains ecoregion in Alberta, Canada. They use modeling to relate % agriculture in the watershed and stream nutrient concentrations. In that method, the y-intercept (i.e., zero agriculture) is used to define 'no impact' (Dodds and Oakes, 2004) and can help define a candidate criterion. For the Northwestern Glaciated Plains in Canada this equals 680 µg TN/L. They also use methods involving fixed percentiles of regional reference (and non-reference) sites. Based on all these methods, they provide a range of TN from 680 to 1,110 µg/L, and recommend 980 µg TN/L as a provisional threshold for prairie stream protection. Using the same methods, they also recommend a provisional TP criterion of 106 µg /L.

Fish biometrics have been developed for warm-water plains streams of Montana (Bramblett et al., 2005). The work was carried out exclusively in Montana, in the Northwest Glaciated Plains and the Northwestern Great Plains ecoregion to the south. Fish biometrics provide a means to address harm-to-use for warm-water fish assemblages. One metric, 'proportion of tolerant individuals'[7], shows significant positively correlation with TKN concentrations and significant negative correlation with DO concentrations. Though no specific TN threshold can be drawn from Bramblett et al. (2005), their findings lend support to our work which shows that elevated TN concentrations impact regional DO (and, in turn, the more sensitive taxa in the warm-water fish assemblage).

Patterns in warm-water plains streams in Wisconsin may be roughly comparable to warm-water streams of the Northwestern Glaciated Plains. Wang et al. (2007) examine Wisconsin warm-water streams (e.g., the Southeast Wisconsin Till Plains ecoregion) and relationships between nutrient concentrations and various warm-water fish metrics. One of the metrics ('% individuals considered intolerant')[8] was significantly correlated (negatively) with TP and TN. (This metric is essentially the mirror image of 'proportion of tolerant individuals' of Bramblett et al. (2005).) Wang et al. (2007) also report changepoint thresholds between nutrients and the metric. Nutrient changepoint thresholds represent concentrations above which warm-water fish assemblages are likely to be substantially degraded (Wang et al., 2007). The '% individuals considered intolerant' metric was found to have an ecological threshold at 70-90 µg TP/L and 540 to 1,830 µg TN/L.

Heiskary et al. (2010) recommend numeric nutrient criteria for rivers in different regions of Minnesota, including the southern region of the state which is warm-water and dominated by the Western Corn Belt Plains ecoregion. They examine relationships between DO concentration and fish metrics (including changepoint thresholds), benthic and phytoplankton algae vs. nutrient concentrations, and DO flux (daily maximum minus the daily minimum) vs. invertebrate and fish metrics. Fish metrics include the '% sensitive fish species' metric comprised of most of the same species used in Wisconsin (Lyons, 1992). Heiskary et al. (2010) recommend a TP criterion of 150 µg TP/L to protect fish and aquatic life in the southern region of Minnesota.

Earlier we presented work showing that in wadeable streams TP is saturated at 24-62 µg TP/L and TN between 367-602 µg/L (Dodds et al., 2006; Suplee et al., in press); our recommended criteria for western MT generally are set within or below those ranges since nutrient levels must be below saturation breakpoints to achieve improvements in algae levels/eutrophication. Natural background concentrations of nutrients in the Northwestern Glaciated Plains ecoregion are already at or above these concentrations (Chambers et al., 2011) (see also **Table 3-6**), and yet harm-to-use thresholds at even higher nutrient concentrations can still be identified. If benthic algae are nutrient-saturated, how is this so? We believe it is strongly related to the basic ecology of these streams. The region's streams tend towards two scenario endpoints: (1) un-scoured streams dominated by macrophytes and benthic algae, and (2) scoured, more turbid streams where phytoplankton can be dominant (Suplee, 2004; Suplee et

[7] The metric is comprised of highly tolerant species, including: goldfish, common carp, fathead minnow, white sucker, black bullhead, and green sunfish (Bramblett et al., 2005).
[8] This metric was specifically designed to assess fish assemblages in perennial warm-water streams of intermediate size (ie., wadeables), and has direct application to southeastern Minnesota as well (Lyons, 1992). The fish comprising the intolerant species list are almost all warm-water species, and a few are even found in this region of Montana (e.g., smallmouth bass, Iowa darter, and silvery minnow; Brown, 1971).

al., 2008, Appendix A). In scenario 2 streams, summer scouring events give phytoplankton a competitive edge because they can tolerate high turbidity by rotating through the water column via wind and flow advection. Higher turbidity surely induces more light limitation, yet summer phytoplankton concentrations can in cases become very high (>70 µg Chl*a*/L; (Suplee, 2004)). Other regional streams have phytoplankton Chl*a* concentrations as high as 516 µg/L (Suplee, 2004). Phytoplankton-dominated wadeable streams are rarely seen in western MT, and were not a meaningful proportion of the datasets used to derive the nutrient saturation levels mentioned above. In the clearer, un-scoured streams (scenario 1), macrophytes can—if stimulated enough by nutrients—impact DO concentrations, especially when they senesce (Jewell, 1971). Macrophytes can gain nutrients from the water but also from the sediments (Chambers et al., 1989), obscuring the direct water column nutrient concentration vs. DO relationship. Dissolved oxygen problems probably need to become fairly severe before notable impacts to plains fishes occur, because these fish are already naturally tolerant (Bramblett et al., 2005). So what we are dealing with here are streams (and associated flora and fauna) of a very different (and more low-DO tolerant) nature relative to western MT, which leads to the higher nutrient impact thresholds observed. That is, to discern a harm-to-use impact in plains streams, levels of nutrients well above the saturation point for algae in non-plains streams are needed in order to override the physical, floral, and faunal differences (and accompanying confounding factors).

Conclusion

Work specific to Montana indicates a TN criterion of 1,400 µg TN/L would maintain DO concentrations at standards common throughout the ecoregion. Studies carried out in warm-water streams in the plains of Canada, in Wisconsin, and in Minnesota provide a range of values from 540 to 1,830 µg TN/L and 70 to 150 µg TP/L. **We recommend 1,400 µg TN/L and 110 µg TP/L.** The TN criterion was derived from a study carried out specifically in this ecoregion in Montana and falls within the range of potential values located in the literature. The TP criterion (110 µg TP/L) is very close to that recommended by Chambers et al. (2011), equates to the 75th percentile of the reference distribution for this ecoregion (**Table 3-6**), and falls within the range of criteria located in the literature.

3.5.1 Transitional Level IV Ecoregions within the Northwestern Glaciated Plains: Sweetgrass Upland (42l), Milk River Pothole Upland (42n), Rocky Mountain Front Foothill Potholes (42q), and Foothill Grassland (42r)

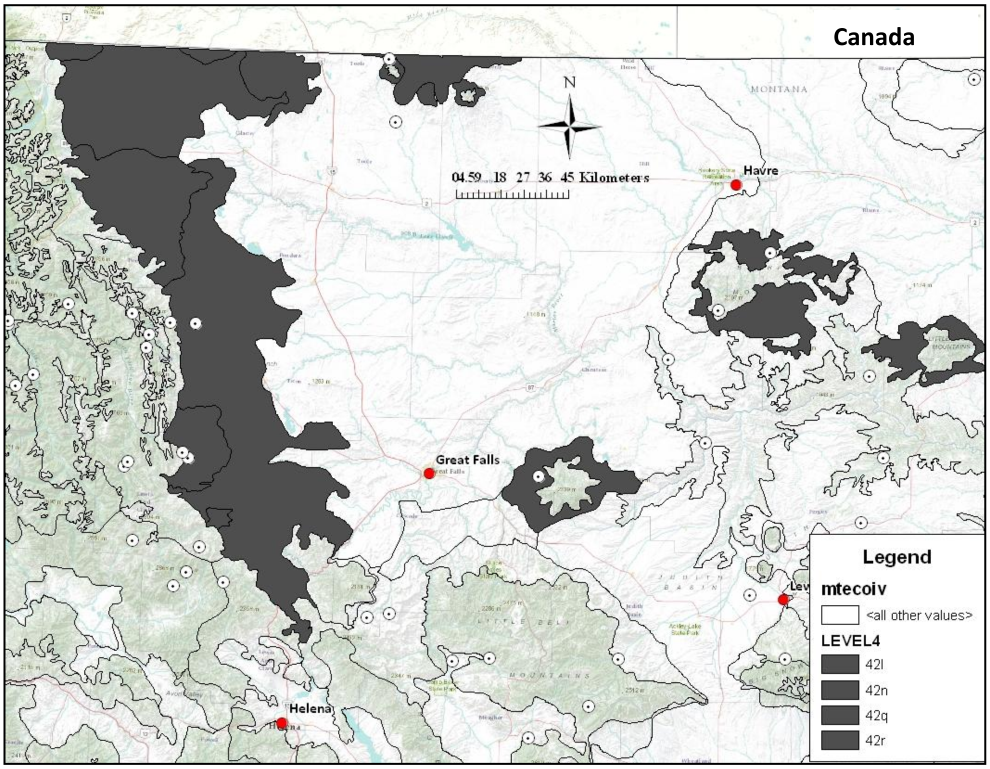


Figure 3-14. Map of Montana showing in gray the transitional level IV ecoregions (42l, 42n, 42q, and 42r) within the Northwestern Glaciated Plains. White dots are the reference sites.

<u>**Recommended Numeric Criteria**</u>
Total Phosphorus: **80 µg TP/L**
Total Nitrogen: **560 µg TN/L**

N:P Ratio of Criteria: **7:1**
N:P Ratio of Reference Sites: **13:1** (Redfield N:P ratio = 7:1)

<u>**Descriptive Statistics of Regional Reference Sites**</u>

Table 3-7. Descriptive Statistics for TN and TP Concentrations in Transitional Level IV Ecoregions (42q, 42r) of the Northwestern Glaciated Plains. No data were available for 42l, 42n.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	5	20	24	2830	115	253	515	704
TP	5	17	1	380	9	20	78	246

The 80 µg TP/L criterion matches to the 75th percentile of reference.
The 560 µg TN/L criterion matches to the 80th percentile of reference.

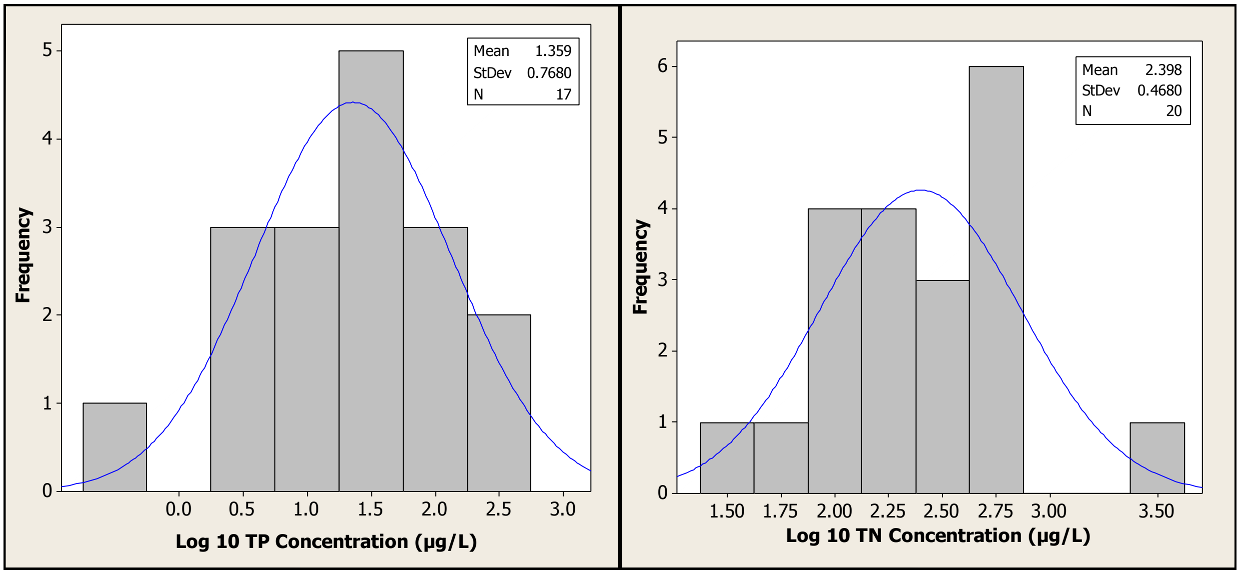


Figure 3-15. Nutrient concentrations from reference streams in the Transitional Level IV ecoregions (42q, and 42r) of the Northwestern Glaciated Plains.
No data were available for 42l and 42n. Data were collected during the Growing Season (June 16-September 30).

Discussion of the Nutrient Criteria for the Transitional Level IV Ecoregions Within the Northwestern Glaciated Plains

In general, streams located in these transitional level-IV ecoregions have more in common with the mountains than the plains. Several lines of information provide support for this. First, although these transitional level IVs form part of the Northwestern Glaciated Plains ecoregion, most of the streams in the transitional level IVs are classified by the state as B-1. This means that they are expected to support salmonid fisheries and are coldwater systems, in sharp contrast to the warm-water streams found further to the east. Clearly, those who developed the stream class system in the late 1950s recognized the strong mountain influences on these streams. Second, floristically they have more in common with mountain streams. Teply and Bahls (2007) carry out a hierarchical cluster analysis on diatom algae (Bacillariophyta) from Montana reference sites, and find that streams of the transitional region are best classified along with the mountain streams. In fact, the level IV ecoregions addressed here (42l, 42n, 42q, and 42r) are being assessed by the Department using diatom metrics designed to evaluate coldwater streams (Teply, 2010; Montana Department Environmental Quality, 2011). Third, although the natural level of nutrients here (**Table 3-7**) are higher than the most nutrient-rich mountain ecoregion (the Middle Rockies, **Table 3-1**), they are still much lower than concentrations observed in the Northwestern Glaciated Plains further to the east (**Table 3-6**).

It is of great interest to note that the TP and TN criteria recommended for the four level-III mountain ecoregions (i.e., 25-30 µg TP/L and 300-350 µg TN/L) fall between the 50th and 60th percentile of reference for these transitional ecoregions (**Table 3-7**). That is, the mountain-ecoregion criteria fall well within the central tendency of the transitional ecoregion's natural background. Some reference streams in the transitional ecoregions also have benthic algae levels that fall close to or are slightly above the recreationally-based threshold (150 mg Chl*a*/m^2; **Table 3-8**). In reference streams of Montana's mountainous ecoregions, we have not measured a site-average benthic Chl*a* level >80 mg/m^2, and the median there is 14 mg Chl*a*/m^2 (Suplee et al., 2009); also recall that nutrient concentrations of reference streams in the mountain ecoregions are usually well below the recommended criteria. Viewed as a whole, this "natural experiment"—represented by the naturally-elevated nutrients and the corresponding algae levels of this transitional region—lends support to the nutrient criteria recommended for the mountainous regions.

Table 3-8. Benthic Algae Levels Measured in Streams of Ecoregions 42r and 42q.

Site Name	Reference Site No.	Ecoregion (level IV)	Sampling Date	Site-average Chl*a* (mg/m^2)
Clear Creek	ClearCre_121_W	42r	9/20/2001	19
Clear Creek	ClearCre_121_W	42r	8/5/2003	29
Clear Creek	ClearCre_121_W	42r	8/7/2003	17
Clear Creek	ClearCre_121_W	42r	9/7/2003	41
Clear Creek	ClearCre_121_W	42r	8/21/2009	37
Barr Creek lower site at Sun River WMA	BarrCree_504_C	42q	7/9/2009	159
Barr Creek lower site at Sun River WMA	BarrCree_504_C	42q	8/6/2009	84
Barr Creek lower site at Sun River WMA	BarrCree_504_C	42q	9/11/2009	95
Rose Creek upstream from confluence with Barr Creek	RoseCree_518_C	42q	7/10/2009	91
Rose Creek upstream from confluence with Barr Creek	RoseCree_518_C	42q	8/8/2009	148
Rose Creek upstream from confluence with Barr Creek	RoseCree_518_C	42q	9/13/2009	60

WMA – wildlife Management Area

It was necessary to derive benthic algae and nutrient criteria specific to these transitional ecoregions since natural levels of nutrients here are equal to or elevated above the mountain criteria, but still below concentrations of the plains. Natural algae levels are high enough (i.e., >125mg Chl*a*/m^2) that seasonal DO problems probably occur in these streams. Therefore, the next beneficial use to consider is recreation. Suplee et al. (2009) show that site-average benthic algal Chl*a* levels of 150 mg Chl*a*/m^2 are acceptable to the public, but 200 Chl*a*/m^2 clearly are not. Since benthic algae levels in this region may naturally reach 159 mg Chl*a*/m^2 (**Table 3-8**), but values >200 mg Chl*a*/m^2 have not been observed, a value of 165 mg Chl*a*/m^2 should be an appropriate target. This is about the highest level (giving consideration to the confidence intervals around the 150 mg Chl*a*/m^2 average) the public would find acceptable (Suplee and Sada de Suplee, 2011).

Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate TN levels that would maintain 165 mg Chl*a*/m^2 benthic algae based on a TP level of 80 µg/L (80 µg TP/L = 75th percentile of reference here). These equations resulted in TN concentrations ranging from 445 to 775 µg TN/L. Also, note that nutrient-benthic Chl*a* regressions have breakpoints at 27-62 µg TP/L and between 367-602 µg/L for TN (Dodds et al., 2006), and, the inherent TN:TP ratio of the region is about 13:1 (higher than Redfield).

Conclusion

Giving consideration to the equations of Dodds et al. (2006), saturation thresholds (Dodds et al., 2006), Redfield ratio, and natural background nutrient levels, we **recommend 80 µg TP/L and 560 µg TN/L for the transitional ecoregions 42l, 42n, 42q, and 42r.** The TN criterion is in the range provided by the equations of Dodds et al. (2006), is lower than the max saturation threshold and, along with TP, provides an N:P ratio of 7:1 (at Redfield). The TP criterion (used to calculate the TN value), having been set to the 75th percentile of regional reference and this should prevent unnecessarily high false positive rates (i.e., declaring a reference stream as impaired) when the Department carries out assessments in this region.

The benthic algal biomass criterion for this region is also adjusted up to 165 mg Chl*a*/m^2 to account for natural background levels, with a corresponding Ash Free Dry Mass (AFDM) value equal to 70 g/m^2 (per AFDM, see Suplee et al., 2009, Table 1)**.**

3.6 Level III: Northwestern Great Plains (Ecoregion 43) and the Wyoming Basin (Ecoregion 18)

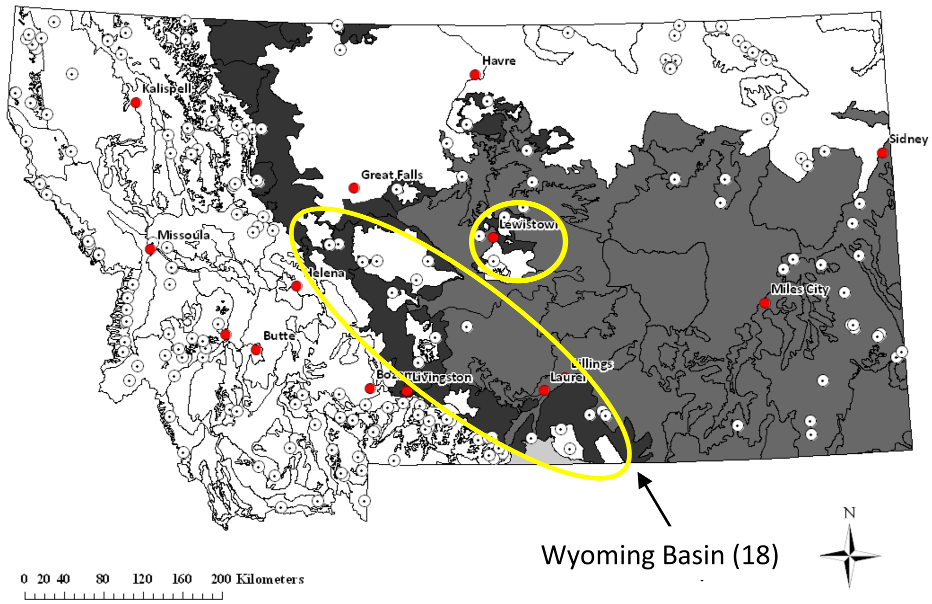


Figure 3-16. Map of Montana showing the Northwestern Great Plains ecoregion (43) in gray, the Wyoming Basin (18) in light gray.
Also, in dark gray, is the mountain-to-plains transitional zone comprising level IV ecoregions in ecoregion 43 (and 42 to the north). Mountain-to-plains transitional level IVs that are part of the Northwestern Great Plains (circled in yellow) were not included among the reference data compiled here. White dots are the reference sites.

<u>**Recommended Numeric Criteria**</u>
Total Phosphorus: **140 µg TP/L**
Total Nitrogen: **1,400 µg TN/L**

N:P Ratio of Criteria: **10:1**
N:P Ratio of Reference Sites: **11:1** (Redfield N:P ratio = 7:1)

<u>**Descriptive Statistics of Regional Reference Sites**</u>

Table 3-9. Descriptive Statistics for TN and TP concentrations in Reference Streams of the Northwestern Great Plains ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	30	100	50	9900	482	792	1389	3141
TP	32	112	1	9911	36	73	137	519

The 140 µg TP/L criterion matches to the 76th percentile of reference.
The 1,400 µg TN/L criterion matches to the 76th percentile of reference.

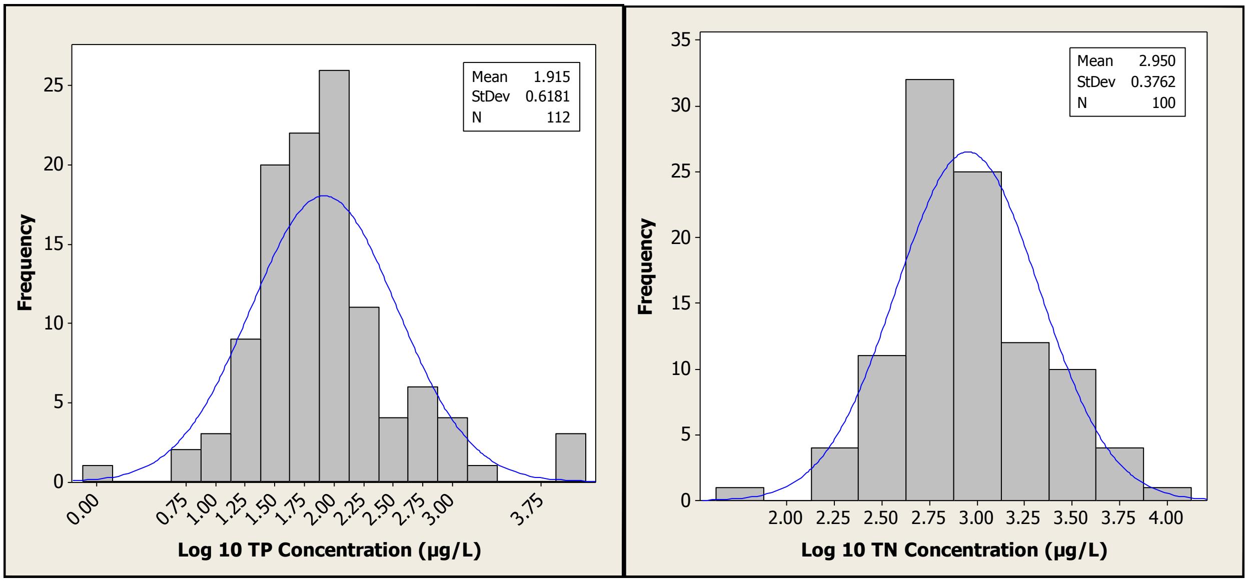


Figure 3-17. Nutrient concentrations from reference streams in the Northwestern Great Plains ecoregion (43), but excluding data from the mountain-to-plains transitional level IV ecoregions 43s, 43t, 43u, and 43v.
Data were collected during the Growing Season (July 1-September 30).

Discussion of the Northwestern Great Plains Nutrient Criteria[9]

The Department (in cooperation with the Carter County Conservation District) carried out a whole-stream nitrogen and phosphorus addition study in Box Elder Creek, a reference stream site located in southeast Montana in the Northwestern Great Plains ecoregion. The full technical report for the study has yet to be prepared, but some of the work has been published (Suplee and Sada de Suplee, 2011). In addition to this study, there are three other studies carried out in plains regions further north and east that should have at least general relevance to this ecoregion (Wang et al., 2007; Heiskary et al., 2010; Chambers et al., 2011).

Appendix B of Suplee and Sada de Suplee (2011) contains key information about the Box Elder Creek dosing study. Additional facts are provided here.

Nutrient dosing took place in summer 2010 and was preceded by "pre" data collection in 2009 and "post" data collected in 2011, at which times no nutrient additions were made. In the study, dissolved sodium nitrate was used as the N source and dissolved dipotassium phosphate as the P source. The High Dose reach was brought up to (after mixing) 150 µg NO_3-N/L and 23 µg SRP/L, continuously, for 53 days in August and September 2010. Ambient nutrient concentrations in summer are normally 3 µg NO_3-N/L and 4 µg SRP/L (or, in totals, about 500 µg TN/L and 54 µg TP/L). Loading calculations showed that the sodium and potassium added to the stream (as part of the compounds used for nutrient additions) increased ambient background of those elements by <0.5% and, therefore, are not considered a significant influence on the results. Benthic algae, stimulated by the nutrient additions, grew to levels far above normal for the stream and led to impacts on DO concentrations when the algae senesced *en*

[9] The level III ecoregion Wyoming Basin (18) has a very small extent in extreme south central Montana (Figure 3-16). No reference data are available there and for purposes of recommending regional nutrient criteria it is being lumped with the Northwestern Great Plains.

masse in early October when the growing season ended. Dissolved oxygen impacts appear to have occurred in patches longitudinally along the stream, with very low DO (zero mg/L) on the bottom in areas where the heaviest densities of decomposing algae settled. The study clearly showed that there is a direct linkage between elevated inorganic nutrients, increased plant growth and, ultimately, impacts to DO standards. Probably the most surprising aspect of the work was that the DO impacts where out-of-phase with peak algal productivity.

Findings from the Box Elder Creek study are generally consistent with the results of the study in Appendix A of Suplee et al. (2008). In that study, DO concentrations—as inferred by diatom taxa—declined when nutrients (TN) became elevated. But what the Box Elder study adds to our understanding is that DO problems may be seasonal and longitudinally patchy in distribution along the stream bottom; in the most impacted locations, DO at the bottom essentially drops to zero. Bramblett et al. (2005), in developing an index of biotic integrity for this region based on fish, find that the 'proportion of tolerant individuals'[10] biometric is significantly correlated (positively) with TKN concentrations and significantly correlated negatively with DO concentrations. We speculate that when nutrient over-enrichment occurs, the more sensitive fish native to these warm-water streams are harmed by patchy, seasonally low DO, and are replaced by tolerant species that can withstand the changes. Indeed, the common carp (*Cyprinus carpio*) is one of the fish in the 'proportion of tolerant individuals' biometric, and is well known for its ability to tolerate very low DO concentrations (Brown, 1971).

Returning to the studies from outside the Northwestern Great Plains ecoregion, Chambers et al. (2011) derive nutrient criteria for prairie streams of the Northwestern Glaciated Plains ecoregion in Alberta, Canada. Models that relate % agriculture in the watershed to stream nutrient concentrations are developed, and the y-intercept of the model (i.e., zero agriculture) defines the 'no impact' level (Dodds and Oakes, 2004). For prairie streams in Canada this equals 680 µg TN/L. They also use other methods involving fixed percentiles of regional reference (and non-reference) sites. Taken together, a range of TN concentrations from 680 to 1,110 µg/L is provided, and they recommend 980 µg TN/L as a provisional threshold. Using the same methods, they also recommend a provisional TP criterion of 106 µg /L.

Wang et al. (2007) examine streams in Wisconsin, including warm-water streams located in plains regions of that state (e.g., the Southeast Wisconsin Till Plains ecoregion). Wang et al. (2007) examine relationships between nutrient concentrations and various warm-water fish metrics, one of which ('% individuals considered intolerant') was significantly correlated (negatively) with TP and TN. (This metric is essentially the mirror image of 'proportion of tolerant individuals' of Bramblett et al. (2005).) Wang et al. (2007) report changepoint thresholds between nutrients and the metric. Nutrient changepoint thresholds represent concentrations above which warm-water fish assemblages are likely to be substantially degraded (Wang et al., 2007). The '% individuals considered intolerant' metric was found to have a threshold between 70 and 90 µg TP/L and 540 to 1,830 µg TN/L (the ranges are due to the different threshold identification techniques used).

Heiskary et al. (2010) recommend numeric nutrient criteria for rivers in different regions of Minnesota, including the southern region of the state which is warm-water and dominated by the Western Corn Belt Plains ecoregion. They examine relationships between DO concentration and fish metrics (including changepoint thresholds), benthic and phytoplankton algae vs. nutrient concentrations, and DO flux

[10] The metric is comprised of highly tolerant species, including: goldfish, common carp, fathead minnow, white sucker, black bullhead, and green sunfish (Bramblett et al., 2005).

(daily maximum minus the daily minimum) vs. invertebrate and fish metrics. Fish metrics include the '% sensitive fish species' metric comprised of most of the same species used in Wisconsin (Lyons, 1992). Heiskary et al. (2010) recommend a TP criterion of 150 µg TP/L to protect fish and aquatic life in the southern region of Minnesota.

Conclusion

A scientific study (Box Elder Creek nutrient dosing) carried out in the Northwestern Great Plains in Montana shows a direct linkage between elevated nutrient concentrations and declines in DO concentration. These DO changes likely impact warm-water fish assemblages and may lead to the undesirable changes in local fish assemblages observed by Bramblett et al. (2005). A study carried out in the Northwestern Glaciated Plains of Montana (Suplee et al., 2008, Appendix A) suggests a criterion of 1,400 µg TN/L to maintain DO concentrations at state standards. Studies carried out in warm-water streams in the plains of Canada, in Wisconsin, and in Minnesota provide a range of values from 540 to 1,830 µg TN/L and 70 to 150 µg TP/L. **We recommend 1,400 µg TN/L and 140 µg TP/L for this ecoregion.** Total nutrient criteria cannot be derived directly from the Box Elder Cr Dosing study at this time, however the TN criterion for the Northwestern Glaciated Plains study (1,400 µg TN/L) is a reasonable surrogate. This is supported by the similarity in the central tendency of the two regions' reference nutrient concentrations (**Tables 3-6 and 3-9**), and a general similarity in the ecology of the streams in the two regions (see the discussion of plains streams ecology in the last paragraph of **Discussion of the Northwestern Glaciated Plains Nutrient Criteria**). A TN concentration of 1,400 µg/L matches the 76th percentile of TN values from the regional reference sites. The TP criterion (140 µg/L) is very close to the one recommended by Heiskary et al. (2010), equates to the 76th percentile of the TP values from the regional reference sites (**Table 3-9**), and falls within the range of criteria from the literature.

Note: No nutrient criteria are being proposed for the River Breaks level IV ecoregion (discussed next). As such, the criteria recommended above for the Northwestern Great Plains would not apply there.

3.6.1 Level IV Ecoregion within the Northwestern Great Plains: River Breaks (43c)

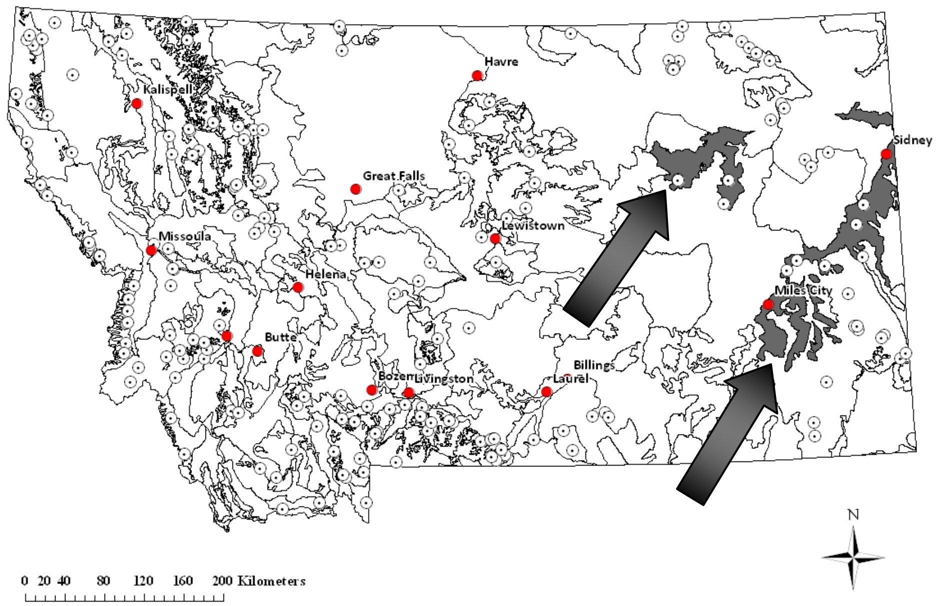


Figure 3-18. Map of Montana showing the River Breaks (43c), a level IV ecoregion within the Northwestern Great Plains ecoregion.
White dots are the reference sites.

Recommended Numeric Criteria
Total Phosphorus: **NONE RECOMMENDED**
Total Nitrogen: **NONE RECOMMENDED**

N:P Ratio of criteria: **n/a**
N:P Ratio of Reference sites: **n/a** (Redfield N:P ratio = 7:1)

Descriptive Statistics of Regional Reference Sites

Table 3-10. Descriptive Statistics for TN and TP Concentrations in Reference Streams of the River Breaks (43c) level IV ecoregion.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	8	28	480	9900	1005	1333	2486	3792
TP	8	29	33	9911	51	129	293	2123

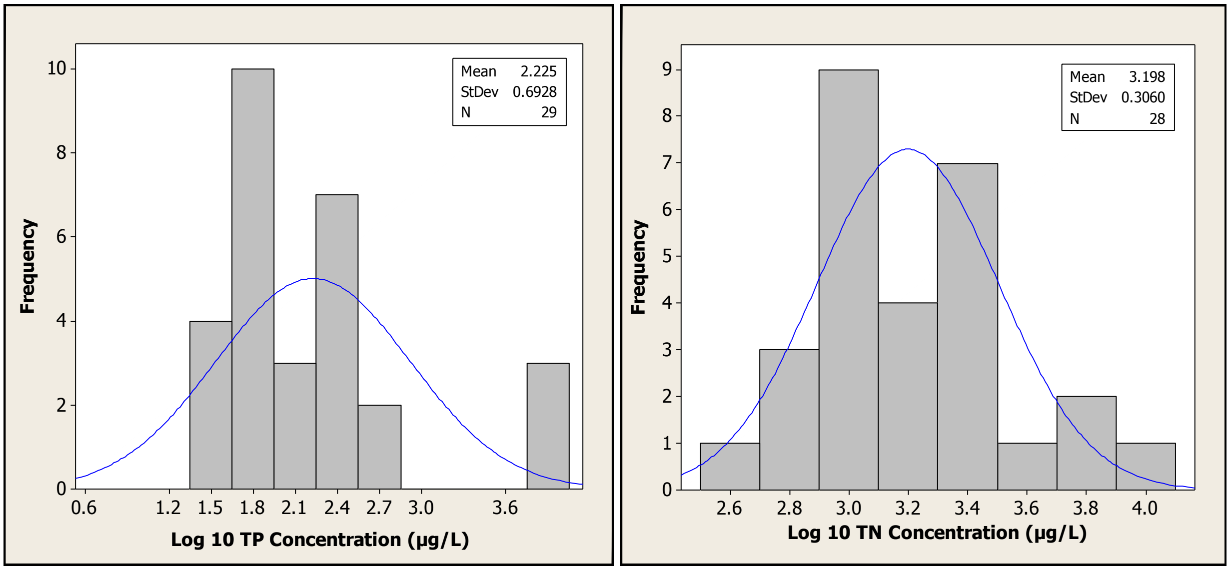


Figure 3-19. Nutrient concentrations from reference streams in the River Breaks (43c) level IV ecoregion.
Data are from the Growing Season (July 1-September 30).

Discussion of the River Breaks (43c) Nutrient Criteria

Average TN concentrations in the reference sites of this level IV ecoregion are higher than harm-to-use levels identified for the Northwestern Great Plains and the Northwestern Glaciated Plains (i.e., 1400 µg TN/L). On the phosphorus side, the TP criterion earlier recommended for Northwestern Great Plains (140 µg/L) corresponds to the 53rd percentile of reference (about average for this ecoregion's reference sites). Clearly these streams have highly elevated nutrient levels naturally, but they also have characteristics that strongly dampen plant growth as they have not been found to develop a robust benthic flora. Highly dissected and erodible terraces and uplands lead to bottomlands of this ecoregion where the soils have poor permeability (Woods et al., 2002). This results in flashy, sediment-laden flows when summer thunderstorms occur. All eight of the reference sites in this region have been found to be extremely turbid when sampled in summer (e.g., as high as 30,000 mg TSS/L with accompanying turbidity of 4,000 nephelometric turbidity units), although by fall in some cases the water has cleared as summer thunderstorms diminish.

Benthic algal growth in these streams (due to the factors above) is usually low (**Figure 3-20),** lower than what is observed in streams for the plains regions as a whole (see data pertaining to the plains in the July 16, 2009 presentation to the Nutrient Work Group, *available at*: http://deq.mt.gov/wqinfo/nutrientworkgroup/AgendasMeetingsPresentations.mcpx). Macrophyte density also tends to be limited. In half of the eight reference streams from this ecoregion no macrophytes were observed at all, in two streams they were present but extremely sparse, and in two streams they were commonly found at sparse to moderate levels along much of the stream channel. As for benthic algae, flashy turbid flows and lengthy periods of high turbidity in these streams prevent a robust benthic flora from developing in many cases, in spite of abundant nutrient availability.

As has been observed in streams along Montana's Hi-line (Suplee, 2004), plains streams can at times develop high levels of phytoplankton Chl*a*. In this ecoregion, especially at these nutrient levels, this occurs in the reference sites as well. Many phytoplankton Chl*a* observations from the reference streams in the River Breaks are low (e.g., < 10 µg Chl*a*/L) but in quite a few cases they can become high (e.g., 72 µg Chl*a*/L, Hart Creek, 7/30/2006; 44 µg Chl*a*/L, Snap Creek, 8/24/2006). Suplee (2004) found that 95% of the phytoplankton samples from reference streams in the Northwestern Glaciated Plains were <20 µg Chl*a*/L. this suggests that—at least sometimes—reference streams of the River Breaks have naturally high phytoplankton Chl*a* concentrations due to the ecological conditions (and elevated nutrients) prevalent in the ecoregion. Whether or not these high levels of phytoplankton Chl*a* affect the region's fish fauna is unknown. In all probability, the more severe physical constraints here (i.e., flashy conditions with extreme levels of suspended sediment) are a far greater constraint on the fish fauna and other aquatic life.

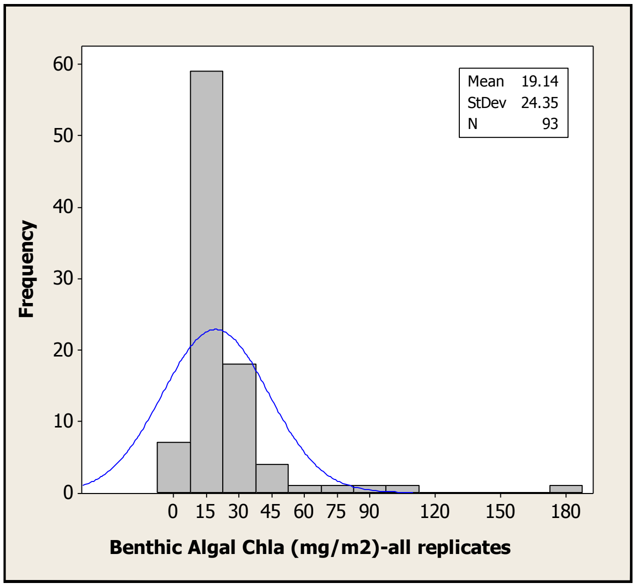


Figure 3-20. Benthic algal density (mg Chl*a*/m2), all replicates, from reference streams in the River Breaks (43c) ecoregion.
Data are from the Growing Season (July 1-September 30).

<u>Conclusion</u>
This level IV ecoregion has highly turbid, flashy streams with naturally elevated TP and TN levels. Concentrations observed in the region's reference sites indicate that nutrient concentrations here are already naturally elevated above the harm-to-use thresholds identified for the plains region as a whole. **As such, no nutrient criteria are recommended for streams within this level IV ecoregion.** Readers should note that the nutrient criteria recommended for the Northwestern Great Plains (level III), discussed previously, would apply across that ecoregion, except here in the River Breaks.

3.6.2 Transitional Level IV Ecoregions within the Northwestern Great Plains: Non-calcareous Foothill Grassland (43s), Shields-smith Valleys (43t), Limy Foothill Grassland (43u), Pryor-Bighorn Foothills (43v), and Parts of the Unglaciated Montana High Plains (43o)[11]

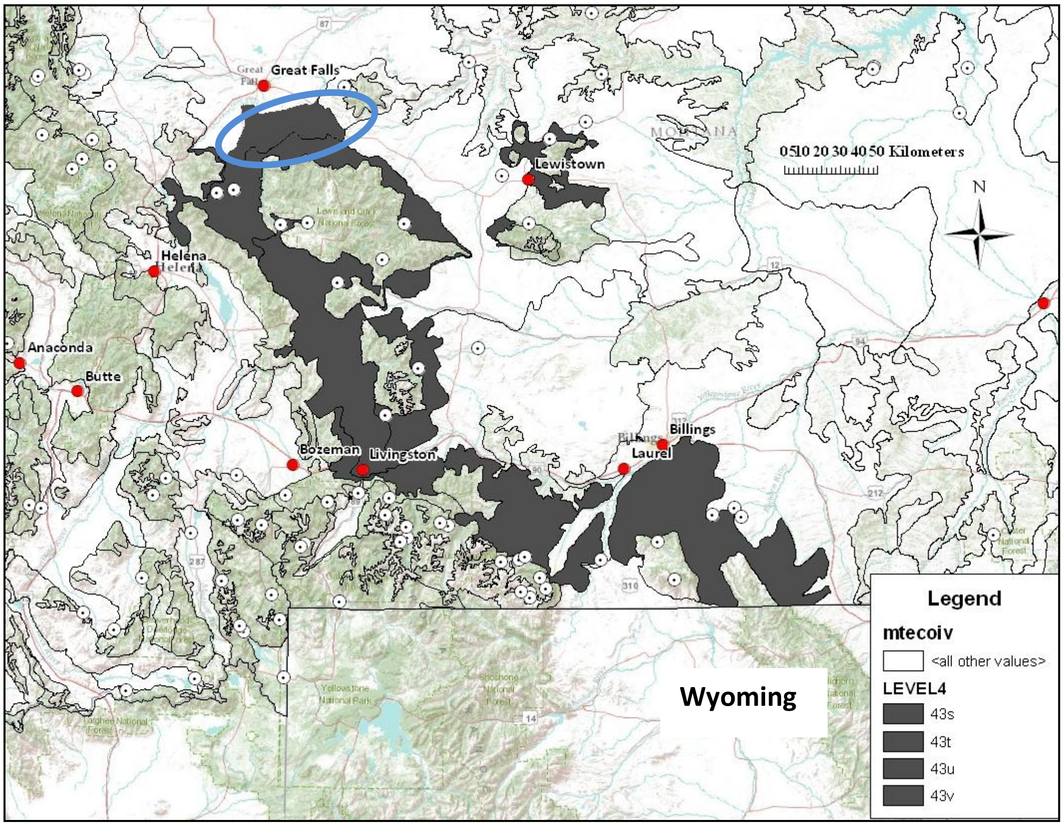


Figure 3-21. Map of Montana showing in gray the transitional level IV ecoregions (43s, 43t, 43u, and 43v) within the Northwestern Great Plains.
The sub-section of ecoregion 43o which is grouped with the preceding is located just south of Great Falls (circled in blue). White dots are the reference sites.

__Recommended Numeric Criteria__
Total Phosphorus: **33 µg TP/L**
Total Nitrogen: **440 µg TN/L**

N:P Ratio of Criteria: **13:1**
N:P Ratio of Reference Sites: **11:1** (Redfield N:P ratio = 7:1)

[11] For the Unglaciated Montana High Plains ecoregion, only the polygon located just south of Great Falls, MT is associated with this transitional region.

Table 3-11. Descriptive Statistics for TN and TP Concentrations in Transitional Level IV Ecoregions (43s, 43t, 43u) of the Northwestern Great Plains. No data were available for 43o, 43v.

			Nutrient Concentration (µg/L)					
					Conc. at given Percentile			
Nutrient	**Number of Reference Sites**	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	12	40	50	753	78	112	174	224
TP	12	40	3	108	6	10	22	34

The 33 µg TP/L criterion matches to the 87th percentile of reference.
The 440 TN/L criterion matches to the 98th percentile of reference.

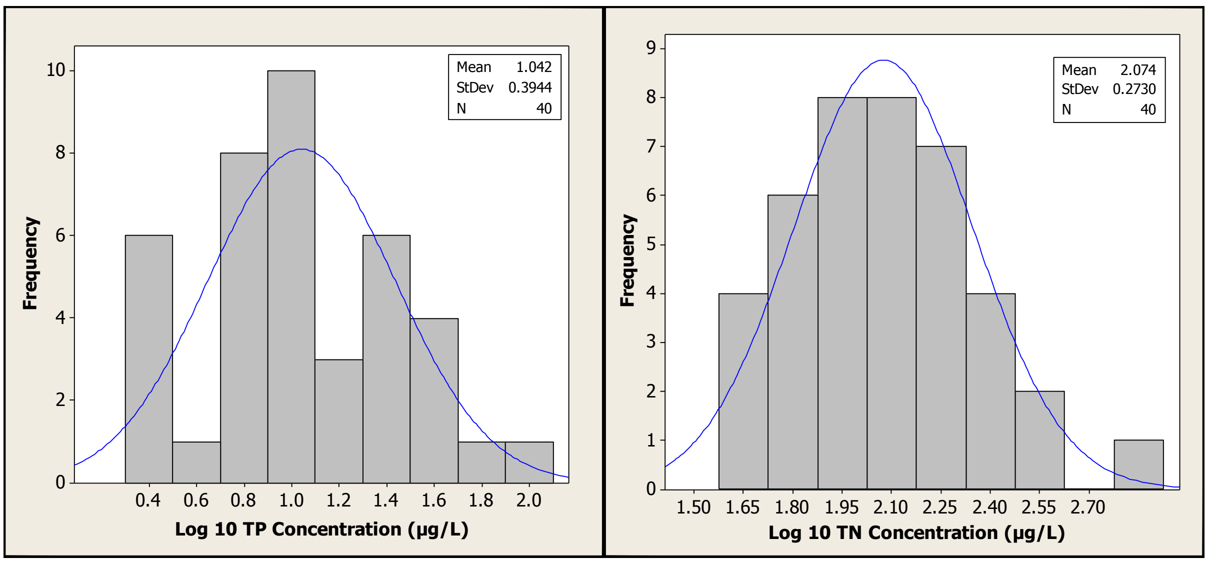


Figure 3-22. Nutrient concentrations from reference streams in the transitional level IV ecoregions (43s, 43t, 43u) of the Northwestern Great Plains.
No data were available for 43o or 43v. Data were collected during the Growing Season (July 1-September 30).

<u>Discussion of the Nutrient Criteria for the Transitional Level IV Ecoregions Within the Northwestern Great Plains</u>

In general, streams located in these transitional level-IV ecoregions have more in common with the mountains than the plains. Several lines of information support this. First, although these transitional level IVs form part of the Northwestern Great Plains ecoregion, virtually all streams in the transitional level IVs are classified by the state as B-1. This means that they are expected to support salmonid fisheries and are generally coldwater systems, in sharp contrast to the warm-water streams found in the Northwestern Great Plains further to the east. It is clear that when the state's stream-class system was developed in the late 1950s, its developers recognized the strong mountain influences on these streams. Second, floristically they have more in common with mountain streams. Teply and Bahls (2007) carried out a hierarchical cluster analysis on diatom algae (Bacillariophyta) from Montana reference sites, and find that streams of the transitional region are best classified along with the mountain streams. In fact, level IV ecoregions addressed here (43s, 43t, 43u, 43v and part of 43o) are being assessed by the Department using diatom metrics for coldwater streams (Teply, 2010; Montana Department Environmental Quality, 2011). Third, the natural levels of nutrients here (**Table 3-11**) are almost the same as the most nutrient-rich mountain ecoregion (the Middle Rockies, **Table 3-1**), but they are much lower than the Northwestern Great Plains further to the east (**Table 3-9**).

In contrast to nutrient concentrations, which are almost the same as the Middle Rockies, site-average benthic algae levels in the transitional region's reference sites are somewhat higher than the Middle Rockies (**Figure 3-23**). Of specific interest is a high average value (170 mg Chl*a*/m^2) from the Elk Creek reference site (reference site No. ElkCreek_511_C; ecoregion 43u). The high benthic algae density likely resulted from the stream's naturally elevated TP, where summer concentrations ranged from 29 to 41 µg/L (average: 31 µg TP/L). However, the data do not suggest that elevated nutrients are a common factor across the level IV ecoregion in which Elk Creek resides (Limy Foothill Grasslands, 43u). Another reference site there (Middle Fork Judith River; MFJudith_513_C) has TN and TP concentrations well below the median of the aggregate reference sites shown in **Table 3-11**.

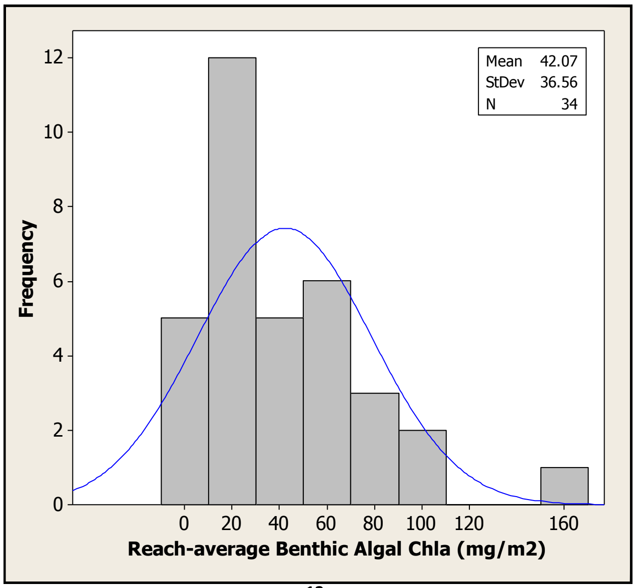


Figure 3-23. Site-average[12] benthic algae density (mg Chl*a*/m^2) from reference streams in the transitional level IV ecoregions (43s, 43t, 43u) of the Northwestern Great Plains ecoregion.

The transitional ecoregions of the Northwestern Great Plains (43s, 43t, 43u) have natural nutrient concentrations with a central tendency almost identical to the Middle Rockies. Further, most reference streams (9 of 10) of 43s, 43t, and 43u have benthic algae levels lower than the thresholds considered throughout this document (125 and 150 mg Chl*a*/m^2). However there is one exception to this, Elk Creek, where benthic algae was above the thresholds. This finding is in contrast to the transitional ecoregions of the Northwestern *Glaciated* Plains (see **Section 3.5.1**), where 2 of 3 reference sites had benthic algae levels above the thresholds; there, higher algae levels (and nutrients) seem to be the norm. Because elevated algae levels seem to be the exception and not the rule here in the transitional ecoregions of the Northwestern Great Plains, we used the 125 and 150 mg Chl*a*/m^2 thresholds to help derive the nutrient criteria. But we did give consideration to the naturally higher TP observed in the Elk Creek site.

[12] A site average is the arithmetic mean of (normally) 11 sample replicates collected along a short stream reach at least 150 m in length using an unbiased systematic approach. See DEQ Standard Operating Procedure manual for benthic Chl*a* (Montana Department of Environmental Quality, 2011).

Elk Creek's average summer TP matches the 85th percentile of the aggregate reference distribution (**Table 3-11**).

Conclusion

Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate TN levels that would maintain 125 and 150 mg Chl*a*/m^2 benthic algae, respectively, based on a TP concentration of 33 µg/L (equal to the 87th percentile of reference and a bit higher than the average concentration observed in the Elk Creek reference site). These equations resulted in TN concentrations ranging from 439 to 1,125 µg TN/L. Also, we bore in mind the fact that nutrient-benthic Chl*a* regressions have saturation breakpoints at 27-62 µg TP/L and between 367-602 µg/L for TN (Dodds et al., 2006). And, as for other ecoregions, we took into account the TN:TP ratio of the region, which is about 11:1 (close to the co-limitation zone). **We recommend 33 µg TP/L and 440 µg TN/L as criteria for the transitional ecoregions 43s, 43t, 43u, 43v, and part of 43o**[11]. The TN criterion matches the 98th percentile of reference for the region. It is also within the range provided by the equations of Dodds et al. (2006), and within the range of saturation thresholds provided by the same authors. Together, the TN and TP criteria provide an N:P ratio of 13:1 (a bit higher than the natural ratio for the region).

4.0 REACH-SPECIFIC NUMERIC NUTRIENT CRITERIA RECOMMENDATIONS

In **Section 3.0**, ecoregions were used as the ecologically-based system for segregating nutrient criteria for different geographic zones. However, The Department recognizes that within each ecoregional zone there are streams with unique characteristics where numeric nutrient criteria must be considered on a case-by-case basis. Conditions that could render the ecoregional criteria inappropriate include, for example, the presence of a large dam-regulated lake or reservoir upstream[13], or the upstream influence of a level-IV ecoregion known to have elevated TP concentrations. A few cases have already been identified, and these are presented here. Readers should note that outside of the specified reaches described here, the ecoregion-wide criteria would apply. The Department recognizes that other reach-specific exceptions to the ecoregional criteria may be identified in the future; these can be addressed on a case-by-case basis going forward.

[13] When it comes to reservoirs and dam-regulated lakes, specific state laws must be considered. Conditions resulting from the reasonable operation of dams on July 1, 1971 are natural (§75-5-306[2], MCA). There may exist reasonably operated dams that, due to the nature of the water releases, characteristics of the reservoir, etc., result in nutrient concentrations (and possibly benthic algal densities) that are higher than the ecoregionally-based criteria recommended. These situations will generally be considered by the Department on a case-by-case basis.

4.1 Flint Creek: From the Georgetown Lake Outlet to The Boundary of Ecoregion 17ak at Latitude 46.4002, Longitude -113.3055

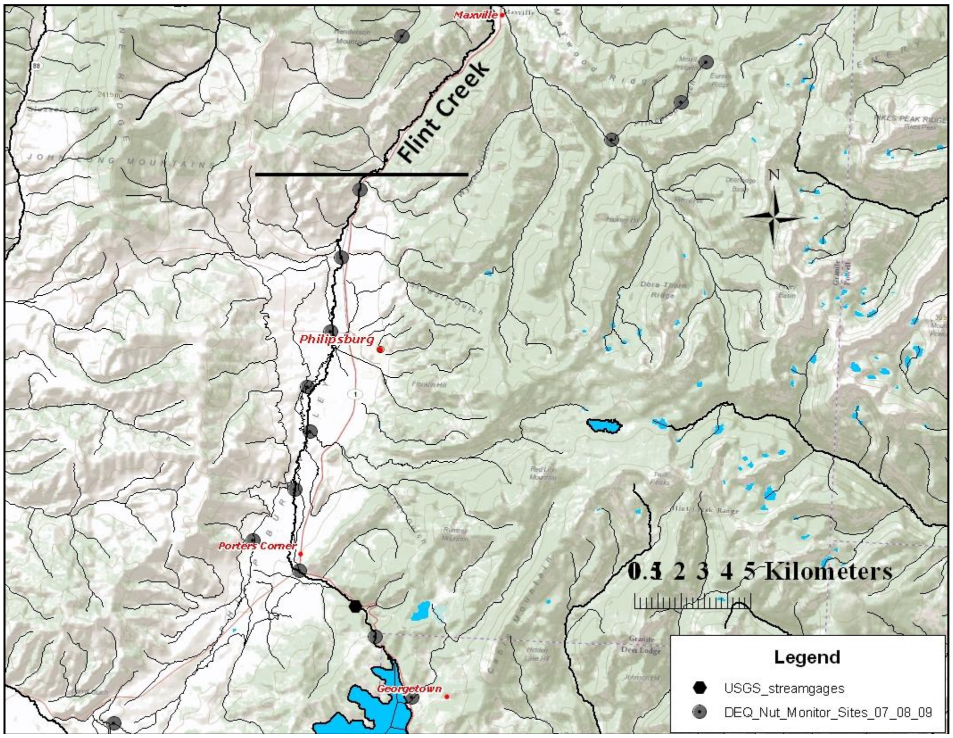


Figure 4-1. Map showing the Flint Creek watershed below the Georgetown Lake outlet.
The criteria presented here would apply from the lake outlet downstream to the black horizontal line, which is the boundary of ecoregion 17ak (Deer Lodge-Philipsburg-Avon Grassy Intermontane Hills and Valleys).

<u>**Recommended Numeric Criteria**</u>
Total Phosphorus: **72 µg TP/L**
Total Nitrogen: **500 µg TN/L**

N:P Ratio of criteria: **7:1**
N:P Ratio of Flint Creek's Water Source: **9:1** (Redfield N:P ratio = 7:1)

Table 4-1. Descriptive Statistics for TN and TP concentrations in Flint Creek.
Just Below Georgetown Lake Outlet (July through September).

		Nutrient Concentration (µg/L)					
				Conc. at given Percentile			
Nutrient	**Number of Samples**	**Min**	**Max**	**25th**	**(Median)50th**	**75th**	**90th**
TN	15	75	1200	239	340	419	585
TP	18	5.0	161	19	36	72	99

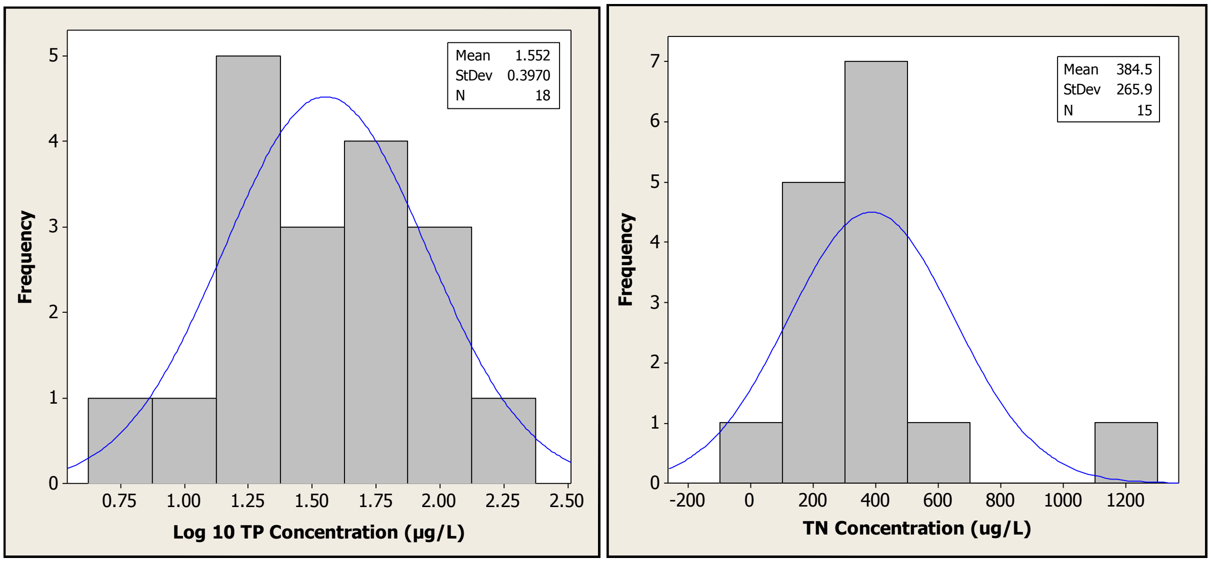


Figure 4-2. Nutrient concentrations observed in Flint Creek just downstream of the point where water exits Georgetown Lake through the dam.
Data were collected during the Growing Season (July 1-September 30).

__Discussion of the upper Flint Creek Nutrient Criteria__
Assessments of Georgetown Lake by the Department in the late 1990s indicated that the lake was fully supporting its beneficial uses. The lake has high levels of internal nutrient loading, particularly for phosphorus, and nutrient concentrations in the hypolimnion can become quite elevated especially during periods when hypolimnetic dissolved oxygen becomes low. The lake's dam forms the headwaters of Flint Creek and the stream receives water from the lake through a 36 inch diameter pipe. Flow into the pipe is controlled by a slide gate at the upstream end of the pipe on the dam. Data collected by the Department indicated that, at times, the intake intersects the lake's hypolimnion and can introduce elevated nutrients to the stream below. State law requires that such 'reasonable dam operations' be considered natural. Therefore we consider the dam operation effect when we developed nutrient criteria for upper Flint Creek.

Table 4-1 and **Figure 4-2** show nutrient concentrations measured in Flint Creek very near to where water comes out of Georgetown dam. These data (collected by the Department and others) were collected between 2005 and 2009 during the July-September period. The data show that the ambient concentrations coming out of the lake are, during the summer when nutrient criteria apply, elevated compared to natural background for the Middle Rockies (**Table 3-1**). The extent to which these conditions persist downstream was also evaluated. This was difficult to determine precisely, but the data suggest (and other Department staff concur) that by Flint Creek station 9 the stream has returned to "normal" Middle Rockies nutrient concentrations. (Station 9 is the gray dot immediately south of the horizontal line dividing Flint Creek in **Figure 4-1.**) Coincidently, station 9 is very near the boundary of ecoregion 17ak so, for ease, we have set the termination point of Flint Creek's reach-specific criteria there.

Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate TN levels that would maintain 125 and 150 mg Chl$a$/m^2 benthic algae, respectively, based on a TP concentration of 72 µg/L (equal to the 75th percentile of the data for Flint Creek just below Georgetown Lake). These equations resulted in TN concentrations ranging from 290 to 637 µg TN/L (290-380 µg TN/L @ 125 mg Chl*a*/m^2, and 394-637 µg TN/L @ 150 mg Chl*a*/m^2). Also, we considered that nutrient-benthic Chl*a* regressions have breakpoints at 27-62 µg TP/L and between 367-602 µg/L for TN (Dodds et al., 2006). (Because of the location of the water out take from Georgetown Lake, Flint Creek starts with TP concentrations already above saturation.) And, we took into account the TN:TP ratio of water in Flint Creek just below the dam, which is about 9:1 (still in the co-limitation range).

<u>**Conclusion**</u>

We recommend 72 µg TP/L and 500 µg TN/L as criteria for the reach of Flint Creek between Georgetown Lake dam and the boundary of ecoregion 17ak, which is located at 46.4002 latitude, -113.3055 longitude. The TN criterion matches the 88^{th} percentile of the water-quality data coming out of the dam into Flint Creek. The TN values calculated for 125 mg Chl*a*/m^2 could not be achieved without requiring that the Georgetown Lake outtake be raised above the level of the hypolimnion (**Table 4-1**). 500 µg TN/L is within the range provided by the equations of Dodds et al. (2006) for 150 mg Chl*a*/m^2, and within the range of saturation thresholds provided by the same authors. Together, the TN and TP criteria provide an N:P ratio of 7:1 (at Redfield). **The benthic algal biomass criterion for this region is set at 150 mg Chl*a*/m^2 to account for the dam-elevated nutrient levels, with a corresponding AFDM value equal to 45 g/m^2.**

4.2 Bozeman Creek, Hyalite Creek, and East Gallatin River

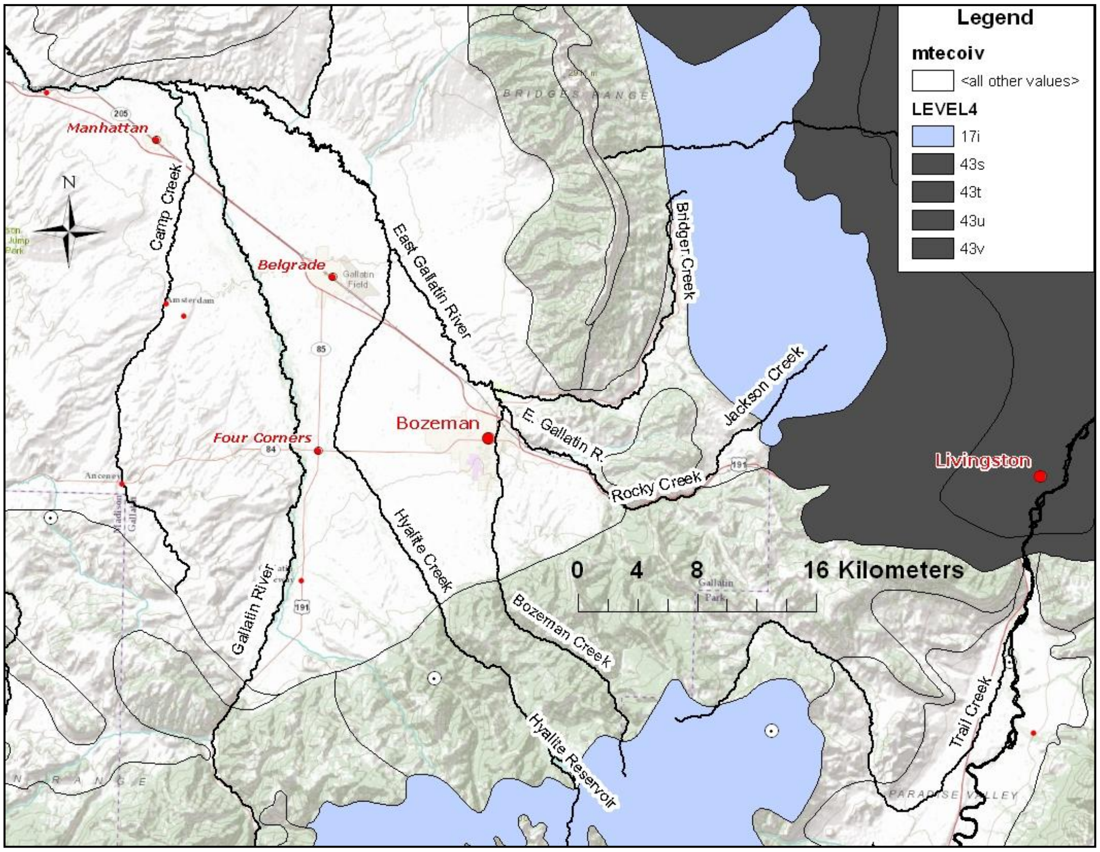


Figure 4-3. Map showing the East Gallatin River watershed, including Bozeman Creek and Hyalite Creek.
Blue shaded areas denote the level IV ecoregion 17i (Absaroka-Gallatin Volcanic Mountains).

Recommended Numeric Criteria

Table 4-2. Recommended Criteria for Reaches of Bozeman Creek, Hyalite Creek, and the East Gallatin River.

Stream Name	Reach Boundaries	TP Criterion (µg/L)	TN Criterion (µg/L)	TN:TP Ratio	Benthic Algal Biomass Criterion
Bozeman Creek	Headwaters to Forest Service Boundary (45.5833, -111.0184)	105	250	2:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Bozeman Creek	Forest Service Boundary (45.5833, -111.0184) to mouth at East Gallatin River	76	270	4:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Hyalite Creek	Headwaters to Forest Service Boundary (45.5833,-111.0835)	105	250	2:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
Hyalite Creek	Forest Service Boundary (45.5833,-111.0835) to mouth at East Gallatin River	90	260	3:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2

Table 4-2. Recommended Criteria for Reaches of Bozeman Creek, Hyalite Creek, and the East Gallatin River.

Stream Name	Reach Boundaries	TP Criterion (µg/L)	TN Criterion (µg/L)	TN:TP Ratio	Benthic Algal Biomass Criterion
East Gallatin River	Reach of East Gallatin River between Bozeman Creek and Bridger Creek confluences	50	290	6:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
East Gallatin River	Reach of East Gallatin River between Bridger Creek and Hyalite Creek confluences	30	300	10:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2
East Gallatin River	Reach of East Gallatin River from Hyalite Creek confluence to the mouth (Gallatin River)	60	290	5:1	125 mg Chl*a*/m^2 and 35 g AFDM/m^2

Discussion of the Nutrient Criteria for Bozeman Creek, Hyalite Creek, and the East Gallatin River

In **Section 3.1.1**, we recommended TP and TN criteria specific to the Absaroka-Gallatin-Volcanic Mountains (17i), a level IV ecoregion with naturally elevated phosphorus concentrations. 'Elevated' means that the phosphorus levels in the ecoregion's reference streams were higher than the Middle Rockies (17) as a whole, and are naturally higher than concentrations that dose-response studies (phosphorus as cause, impact to stream beneficial use as effect) applicable to western Montana indicate are protective of beneficial uses.

The Hyalite Creek and Bozeman Creek watersheds contain parts of 17i, have documented elevated TP concentrations in surface water, and mapped Phosphoria formations within their boundaries (United States Geological Survey, 1951). Hyalite Creek and Bozeman Creek are in adjoining drainages and flow northward before joining the East Gallatin River (**Figure 4-3**). Bozeman Creek flows into the East Gallatin River at Bozeman, MT and Hyalite Creek joins the East Gallatin River northeast of Belgrade, MT. The headwaters of Jackson and Bridger creeks also fall within 17i, but that particular area does not have identified geologic sources of phosphorus or water quality data that suggest elevated phosphorus concentrations in surface water, and are not included in this discussion.

Reach-specific Methods

Nutrient data at the 75th percentile of reference for the Absaroka-Gallatin-Volcanic Mountains (17i) and the Middle Rockies (17) were used to determine the potential natural background of streams that flow through both ecoregions, and for waterbodies that receive drainage from both ecoregions (**Table 4-3**). Relative flow contributions were calculated from available discharge data from the USGS and from flow sampling projects conducted by the Department and its contractors. These flow estimates were used to determine the relative contribution from each ecoregional zone and, in turn, determine the potential natural background nutrient concentrations of each stream or stream segment using the following equation:

$$NB_{\mathbf{NEW}} = \frac{(NB_1 * Q_1) + (NB_2 * Q_2)}{Q_1 + Q_2}$$

where NB_1 is the nutrient concentration (either N or P; µg/L) at the 75th percentile of the reference sites for ecoregion 17i, NB_2 is the nutrient concentration (either N or P; µg/L) at the 75th percentile of the reference sites for ecoregion 17 (Middle Rockies), Q1 and Q2 are the average summer flows (L/sec) that can be allocated to each ecoregional zone, and NB_{NEW} is the calculated natural-background nutrient concentration (µg/L) for the stream after having accounted for the mixing of the two water sources.

If the calculated natural background concentration in a given stream was equal to or greater than the recommended N or P criteria for the ecoregion in which the stream resides, a site-specific analysis was used to calculate the new criterion based on the estimated flow contributions from the different ecoregions. The new criterion was then derived using the mixing equation given above and using the draft ecoregional criteria (**Table 4-3**).

Table 4-3. Ecoregion-specific Reference Conditions and Numeric Nutrient Criteria for TN and TP

	75th percentile - Reference Condition		Draft Numeric Nutrient Criteria	
	TN	**TP**	**TN**	**TP**
Level III Middle Rockies	141	20	300	30
Level IV Absaroka-Gallatin-Volcanics	100	105	250	105

All values are in µg/L

For example, in Bozeman Creek discharge records established that 63.4% of the flow at the mouth (1313.86 L/sec) originates upstream of the forest boundary (green area **in Figure 4-3**) where ecoregion 17i's TP concentrations are above the natural background for the Middle Rockies ecoregion. The balance of flow (36.6%; 481 L/sec) originates from below the forest boundary. Natural background (NB) for TP was therefore calculated as:

([105 µg TP/L * 833 L/sec] + [20 µg TP/L * 481 L/sec]) ÷ (833 + 481 L/sec) = 74 µg TP/L

A reach-specific criterion was then calculated for TP using the ecoregional numeric criteria:

([105 µg TP/L * 833 L/sec] + [30 µg TP/L * 481 L/sec]) ÷ (833 + 481 L/sec) = 76 µg TP/L

The results are shown below in **Table 4-4.**

Table 4-4. Total Phosphorus Natural Background and Derived Nutrient Criteria for Stream and River Reaches in the East Gallatin River Watershed.

	Bozeman Creek (Forest Service boundary to mouth)	**East Gallatin R. between Bozeman and Bridger Creeks**	**East Gallatin R. between Bridger and Hyalite Creeks**	**Hyalite Creek (Forest Service boundary to mouth)**	**East Gallatin R. between Hyalite Creek and Gallatin River**
Natural Background	74	40	30	80	50
Reach Criterion	76	50	30	90	60

All values are in µg/L

Total phosphorus concentrations are directly affected by natural sources from ecoregion 17i in the Hyalite and Bozeman creek drainages (**Table 4-3**). Natural background for TP is at or above the numeric standard for the Middle Rockies ecoregion in every reach downstream of the phosphorus source area.

In the case of the East Gallatin between Bridger and Hyalite Creeks, the natural background concentration is equal to the draft numeric criteria for the Middle Rockies Level III ecoregion. Therefore, it was not necessary to change the normal Middle Rockies TP criterion for that reach. Data collected in 2008 and 2009 below the Bridger Creek confluence with the East Gallatin River and above the City of

Bozeman WWTP discharge (*n*=5) had a mean of 22 µg TP/L with a maximum of 26 µg TP/L. These data lend support to the decision to not raise the draft numeric water quality criterion above 30 µg TP/L for this segment.

For waterbodies receiving significant flows from ecoregions with natural sources of phosphorus, adjusted downstream criteria for TN may be slightly lower based on the same equations and process described above (**Table 4-5**).

Table 4-5. Total Nitrogen Natural Background and Derived Criteria for Stream and River Reaches in the East Gallatin River Watershed.

Total Nitrogen	Bozeman Creek (Forest Service boundary to mouth)	East Gallatin R. between Bozeman and Bridger Creeks	East Gallatin R. between Bridger and Hyalite Creeks	Hyalite Creek (Forest Service boundary to mouth)	East Gallatin R. between Hyalite Creek and Gallatin River
Natural Background	120	130	140	110	130
Reach Criterion	270	290	300	260	290

All values are in µg/L

Note that for Bozeman and Hyalite creeks, the criteria applicable to ecoregion 17i (105 µg TP/L and 250 µg TN/L) apply to those streams from their respective headwaters down to the Forest Service boundary.

<u>Conclusion</u>

Equations relating benthic algal Chl*a* to total nutrients (Dodds et al., 1997, Equation 17; Dodds et al., 2006; Equation 19) were used to calculate the benthic Chl*a* biomass that would occur at the criteria levels shown for the stream and river reaches shown in **Table 4-2**. In all cases, benthic algae were maintained at ≤ 125 mg Chl*a*/m^2, therefore that value (and the accompanying AFDM value) is an appropriate and realistic level for these stream segments. The nutrient criteria are adequate to protect the coldwater fisheries use by assuring that dissolved oxygen levels always remains above standards.

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